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ELEMENTS

OF

NATURAL PHILOSOPHY,

DESIGNED FOR

ACADEMIES AND HIGH SCHOOLS.

BY ELIAS LOOMIS, LL.D.,

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WITH THREE HUNDRED AND SIXTY ILLUSTRATIONS.

NEW YORK:

HARPER & BROTHERS, PUBLISHERS,

FRANKLIN SQUARE.

1858.

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PREFACE.

NATURAL PHILOSOPHY has long been regarded as forming an essential part of a course of liberal education, and every year it is becoming more generally introduced into academies and high schools. An acquaintance with the principles of this science can not be too widely diffused; but it is to be regretted that this study should so often degenerate into a mere statement of facts and conclusions, without any intelligible view of the evidence upon which such conclusions are founded. The teacher who contents himself with stating scientific results without the reasons for his conclusions, not only sacrifices the primary object of an education, but inflicts positive mischief upon his pupils by habituating them to accept the most important conclusions dogmatically announced. The primary object in education should be to cultivate philosophical habits of mind; to teach the art of reasoning, and of deducing correct conclusions from premises; and no study is better adapted to secure these objects than that of Natural Philosophy when properly pursued. In some branches of this science, especially Mechanics and Optics, a constant application of mathematical principles is not only useful, but almost indispensable; so that it is quite impossible to give even a tolerable idea of the present state of these branches without assuming some mathematical knowledge on the part of the learner.

In the present volume I have attempted to exhibit the leading principles of Natural Philosophy in a methodical and scientific form, without any use of the mathematics beyond the first elements of Algebra, Geometry, and Plane Trigonometry. Every principle is enunciated clearly and concisely, and, as far as practicable, I have exhibited the evidence upon which every principle rests. Even when the full demonstration involves an acquaintance with the more difficult parts of the mathematics, I have endeavored to give an outline of the philosophical principles upon which the mathematical demonstration is founded. Those principles which are considered specially important have been printed in italics, so as readily to attract the attention of the pupil. While the leading object has been to teach general principles, care has been taken to combine with them a variety of useful information, and particularly to give an account of many recent discoveries in every branch of the science.

It is hoped that this volume may contribute to diffuse a more general taste for scientific studies, as well as an acquaintance with the fundamental principles of Natural Philosophy.

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NATURAL PHILOSOPHY.

BOOK FIRST.

MECHANICS.

SECTION I.

PROPERTIES OF MATTER.

ART. 1. *Natural Philosophy is the science which treats of the general properties of unorganized bodies, and of the laws which they obey.*

All bodies which have life, such as animals and plants, have peculiar *organs*, which are adapted to secure their continued life, growth, and activity. Thus, in the human body, we find lungs for inhaling the air, veins for conveying the blood, nerves for sensation, etc. It does not belong to Natural Philosophy to inquire into the structure or office of these organs, or into any of the peculiarities of *organized* bodies.

2. Natural Philosophy may be divided into *Mechanics*, *Hydrostatics*, *Pneumatics*, *Acoustics*, *Heat*, *Optics*, *Magnetism*, and *Electricity*.

3. By *law* we understand the mode in which the powers of nature act. Thus the force of magnetic attraction is found to vary inversely as the square of the distance; hence this is called the law of magnetic attraction.

Science assumes for its basis that the laws of nature are *constant;* that is, a law discovered in America must hold true in Europe, and a law discovered during the present century must hold true for any other time, whether past or future.

4. *Body* is a limited portion of matter.

Matter is that which is extended in three dimensions, and is impenetrable.

Void space has extension in three dimensions; that is, has length, breadth, and thickness; but it is not impenetrable. Thus a void space of one cubic inch may be filled by a cubic inch of brass or any other form of matter; but the space which is occupied by a cubic inch of brass can not be occupied at the same time by a cubic inch of steel.

5. Matter occurs under three different forms—*solid, liquid,* and *gaseous.*

A solid body is one whose parts cohere with such force that it maintains its figure unless subjected to some force greater than its own weight. Thus a piece of iron, stone, or wood, laid upon a plane surface, does not change its figure in consequence of its own weight.

A liquid body is one whose parts cohere slightly, but not with sufficient force to prevent a change of form by the mere influence of their weight. Thus a mass of water, dropped upon a plane, will, in consequence of its own weight, spread itself over the surface of the plane.

Solids in a state of minute division must not be confounded with liquids. Sand consists of a great number of small particles, each of which has the properties of a solid as truly as the largest rock. If the particles of sand be examined with a microscope, each will be found to maintain its figure in virtue of the cohesion of its atoms.

6. *A gaseous body* is one whose particles are not held together by mutual cohesion, but have for each other a repulsion, in virtue of which they tend to separate, so that the whole mass has the power of indefinite expansion.

If a quantity of air be confined in a cylinder under a piston which moves air-tight in the cylinder, and the piston be elevated, the air will not remain at the bottom of the cylinder, as a liquid would do, but it will expand and fill the entire augmented space under the piston.

In some instances the same substance exhibits successively each of these states of solid, liquid, and gaseous, as ice, water, and steam.

7. Matter, under each of these forms, exhibits certain properties, some of which are called *primary,* being such as are common to all bodies, and without which we can not conceive of their ex-

isting, while others are called *secondary* or *accessory*, and are not necessary to our conception of a body's existence.

8. *The primary properties* of all bodies are extension and impenetrability.

Extension is that property in consequence of which every body occupies a certain space. The extension of bodies is expressed by three dimensions, length, breadth, and thickness.

This property alone does not define matter, for mere space has the same property.

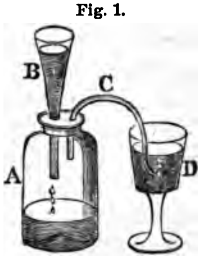
9. Matter is also *impenetrable;* by which we mean that one body can not enter into the space occupied by another, without previously thrusting the latter from its place.

This is true alike of solids, liquids, and gases.

When a nail is driven into wood, the particles may appear to be penetrated, but, in fact, they are merely displaced.

If a hollow cylinder into which a piston is accurately fitted be filled with water, the piston can not be thrust into the water, thus showing that the water is impenetrable.

Fig. 1.



The following experiment illustrates the impenetrability of air.

Take a bottle, A, with two necks or apertures. In one aperture insert a funnel, B, and in the other insert one end of a bent tube, C, while the other end is immersed in a tumbler of water, D. If water be poured into the funnel, as it descends into the bottle, the air escapes through the tube, as is shown by the ascent of bubbles in the water in the tumbler.

If we depress an inverted tumbler in a vessel of water, the air will exclude the water from the tumbler. The diving-bell is constructed upon this principle.

Space without impenetrability is called *void space*, or a vacuum.

10. The *secondary* properties of matter are,

First, Indestructibility.

We are unable to *create* or *destroy* a particle of matter, although to a superficial observer the contrary may in some cases appear to be true. Thus, when we burn a piece of paper or wood, a portion of the solid assumes the gaseous form, and only ashes remain; but if these gases are caught in a receiver, as may be

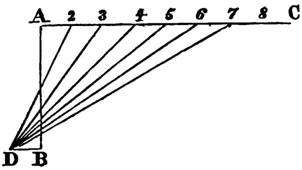
done when the body is burned in a close vessel, they will be found, together with the ashes, to be exactly equal in weight to the body burned.

So, when water is evaporated, the weight of the vapor is exactly equal to that of the water, as may be shown by receiving the vapor in a separate vessel and cooling it, when it will return to the liquid form.

11. *Second, Divisibility.*

A geometrical magnitude, like a line, may be conceived to be divided into *an infinite number of parts.* Let AB be a line of any proposed length; draw AC, BD, at right angles to it; and upon AC take A2, 2 3, etc., each equal to BD. Join D2, D3, etc. The line D2 will cut off $\frac{1}{2}$ of AB, D3 will cut off $\frac{1}{3}$ of AB, D4 $\frac{1}{4}$, etc. Now, as there is no limit to the number of equal parts which may be taken on AC, so there is no fraction so small that a smaller one may not be cut off from the line AB; in other words, the line AB may be divided into an infinite number of parts.

Fig. 2.



12. The *practical division of matter* by mechanical means is subject to limitation; but the following examples show that it may be divided into parts exceedingly minute.

Gold-leaf has been obtained $\frac{1}{360000}$ of an inch in thickness; nevertheless, such a leaf completely conceals the object which it is used to gild.

The film of a soap-bubble, just before bursting, is less than one millionth of an inch in thickness; and, since this film possesses the properties of water as truly as an ocean, it follows that the molecules forming water must be less than one millionth of an inch in diameter.

13. *Matter in solution* is still more wonderfully divisible. With one grain of indigo 10 pounds of water may be tinged blue. These 10 pounds of water contain about 60,000 drops. Suppose that 100 particles of indigo are required in each drop to produce a uniform tint, it follows that one grain of indigo has been divided into 6 million parts.

14. The *blood of animals* consists of small red particles of solid

matter swimming in a transparent fluid. In the human blood these particles are flat and nearly circular, about $\frac{1}{3500}$ inch in diameter. In a drop of human blood, such as would hang from the point of a fine needle, there must be about three millions of these disks.

15. The *microscope* has disclosed the existence of animals, a million of which do not exceed the bulk of a grain of sand. The shells of these animalcules exist in such prodigious quantities, that extensive strata of rocks consist almost entirely of them. One cubic inch of this rock has been estimated to contain about 41 thousand millions of these animals.

16. The *sense of smell* frequently detects the presence of matter so subtle as to escape the perception of our sight and touch.

A *single grain of musk* diffuses through a large room a powerful scent that frequently lasts for years.

17. Although matter may be divided into particles exceedingly minute, there is probably *a limit* to this division, and all matter probably consists of *ultimate molecules* of determinate figure. The phenomena observed in the *process of crystallization* lead to this conclusion.

18. If we heat a quantity of water containing *salt in solution*, the water will evaporate, and the evaporation may be continued until there is no longer sufficient water to hold in solution all the salt. Some particles of salt will thus be left in the water undissolved; but these particles, instead of collecting in irregular masses, will form regular figures bounded by plane surfaces united in regular angles—these figures being invariably the same for the same species of salt, but different for different species. As these crystals increase in size, they always preserve their original figure. Hence the particles of salt must have such a shape that by attaching themselves to the crystal they will maintain the same angles of the bounding planes, and also the atoms must all attach themselves in particular positions, which are not regulated by chance.

Fig. 3.

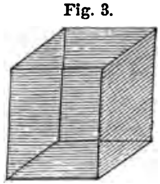


Fig. 4.

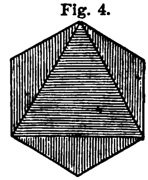


Fig. 3 represents a crystal of common table salt; *Fig.* 4 represents a crystal of alum.

19. Hence we conclude that all substances which are suscep-

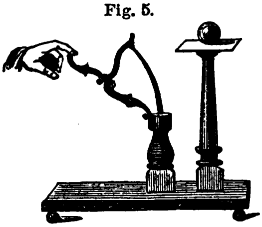
tible of crystallization consist of ultimate atoms of a determinate figure; but all solid bodies are susceptible of crystallization; liquids also crystallize in freezing, and several of the gases have been reduced to the liquid and solid form. Hence it is probable that *all bodies* are composed of ultimate atoms having determinate shape and magnitude. These atoms are so minute that they can not be separately observed by any means that art has hitherto contrived.

20. *Third, Inertia.*

Inertia is that property of matter by which it tends to retain its present state, whether of rest or motion.

Inanimate matter has no power to move itself when at rest, neither has it power to stop itself when in motion. Whatever be its state of rest or motion, in that state it must continue so long as it is not affected by any external force. This principle may be illustrated in various ways.

Fig. 5.



If an ivory ball be placed upon a stiff card, the card may be knocked from under it by a sudden blow without disturbing the ball.

If a cylindrical vessel containing mercury be made to revolve rapidly, the mercury will continue to revolve after the vessel is stopped.

If a horse moving with great speed suddenly stops, the rider is projected forward; or if a horse, from rest, starts suddenly forward, the rider is thrown backward.

21. *Fourth, Weight.*

All material bodies have weight. This is a consequence of the earth's attraction, by which they are drawn toward the earth. A falling body tends toward the *centre of the earth*, because it is attracted by *every particle* of the earth, not because the particles at the centre have a greater attraction than any other particles. The same would be true if the earth were a hollow sphere.

There is no material body which is exempt from the earth's attraction. If some objects, like smoke, or a balloon, seem *not* to be attracted, it is only because they are immersed in the air—a fluid heavier than themselves.

In like manner, a cork plunged in water immediately rises to the top, not because it is *not attracted* by the earth, but because the water is *more attracted* than itself, and therefore displaces the cork. In a vacuum, the lightest objects fall with the velocity of metallic bodies.

22. *Fifth, Porosity.*

Between the molecules which form the mass of a body there are vacant spaces called *pores.* This is proved by a variety of facts.

If 66 quarts of water be mixed with 100 quarts of alcohol, the compound will contain but 162 quarts. This result demonstrates that there must be unoccupied space between the atoms of one or both of these liquids.

When water and sulphuric acid are mingled, the volume of the mixture is less than the sum of the volumes of the ingredients.

A great quantity of cotton may be introduced into a vessel entirely filled with alcohol, without causing the alcohol to overflow.

Mercury will force its way through the pores of lead, of gold, and, indeed, of most of the metals.

By severe pressure, water may be forced through the pores of gold.

23. *Sixth, Compressibility* and *Expansibility.*

Matter in every form, whether solid, liquid, or gaseous, may be compressed.

The compressibility of air is shown by subjecting a confined mass of air to pressure. This is readily done by employing a bent tube closed at one end. There appears to be no practical limit to the compression of which air is susceptible.

Water may be compressed in a similar manner, but it requires very great pressure to produce any sensible effect.

In the process of coining, metals are exposed to powerful pressure, by which they become denser than before, so that the coin has a volume sensibly less than the blank piece before it was struck.

24. Matter in every form is *expanded by heat.*

The expansion of air may be exhibited by means of a glass retort with its neck plunged under water.

The expansion of water may be shown by inclosing it in a glass globe attached to an open tube of small bore, as in the arrangement of a thermometer.

The expansion of metal may be proved by a ball and a ring which exactly fits it at a certain temperature. At a higher temperature, the ball will not pass through the ring.

25. *Seventh, Elasticity.*

Elasticity is that quality by which bodies, after being compressed, endeavor to recover their original shape.

When an ivory ball is suffered to drop on a marble slab, it rebounds. If the marble be smeared with a thin coating of oil, on examining the ball after collision, it will be found that a considerable circular space has been stained by the oil.

If the ball be brought gently into contact with the marble, only a minute space will be stained by the oil. We hence conclude that the force of the impact *flattens* the surface of the ball to an appreciable extent; that, in virtue of its elasticity, the ball recovers its spherical figure, and the force with which it recovers this figure causes the rebound.

Glass and steel possess the same property in a high degree; lead and clay possess this property in a feeble degree.

The elasticity of steel is shown in the tuning-fork.

Glass, when drawn into a fine thread, is highly flexible.

26. If a steel wire be twisted, it tends immediately to recover its first position. The force here exhibited is called the *elasticity of torsion.* This principle has been applied to measure small forces with great accuracy, such as the forces of magnetic and electric attraction.

The elasticity of lead is shown by twisting a lead wire. Even a rope of soft clay exhibits some elasticity under the same circumstances.

27. All bodies are elastic *within certain limits.* There is generally a limit beyond which the molecules of a body can not be deranged, without a permanent change in the form of the body. This limit is different in different substances.

All liquids which have been compressed, immediately recover their original dimensions when relieved from the compressing force, and may therefore be said to be perfectly elastic. The degree of compression which liquids admit is, however, so small,

that they are ordinarily regarded as incompressible and inelastic.

Compressed air recovers its original volume as soon as the pressure is removed, although it may have been confined for years.

28. The peculiar elasticity of some solids depends upon their *temper*, a property which is generally imparted by sudden cooling. If steel be raised to a white heat, and then plunged into cold water, it becomes very elastic and brittle. The fracture shows a crystalline structure.

Glass is capable of receiving a temper. If drops of melted glass be let fall into water, they suddenly solidify at the surface, and the molecules assume a state of tension analogous to that of tempered steel. Pieces of glass of this kind are called *Prince Rupert's Drops.* They will bear the moderate blow of a hammer if lying on a smooth table; but if the point of a drop be broken off, the whole will explode into a fine powder. By holding it under water in a glass vessel, the vessel is sometimes shivered.

The drops lose their peculiar property by being heated and suffered to cool slowly.

SECTION II.

MOTION AND THE LAWS OF MOTION.

29. That branch of Natural Philosophy which treats of the action of forces on bodies is called *Mechanics.*

That part which treats of forces in equilibrium is called *Statics*, and that which treats of motion is called *Dynamics.*

30. *Force* is any cause which moves or tends to move a body, or which changes or tends to change its motion.

Inertia is that property by which a body resists all change of its condition in respect to rest or motion. If a body be at rest, it will oppose resistance to the action of any force; and if it be in motion, and be urged to move faster or slower, it will oppose an equal resistance to change.

31. A body is in a state of *absolute rest* when it continues in the same position in space. We know of no body absolutely at rest; for the earth and the heavenly bodies are known to be in motion.

A body is *relatively at rest* when it preserves the same position in respect to other bodies which we may regard as fixed.

A body is said to be in *absolute motion* when it is moving from one point of space to another, as is the case with the planets.

A body is said to be in *relative motion* when it is moving with respect to some other body.

Thus a man in a vessel may be at rest with respect to the several parts of the ship, while he is in a state of absolute motion. If he walks across the deck, he has a motion relative to the deck. If his own progressive motion from stem to stern were exactly equal to the progressive motion of the ship, he would be at rest with regard to the surface of the sea.

32. The simplest principles to which the phenomena of motion can be reduced, have been given by Newton in the form of Mechanical Axioms, or *laws of motion*. They are the following:

LAW I.—*Every body continues in its state of rest, or of uniform motion in a straight line, unless acted upon by some external force.*

Matter in its unorganized state is inanimate or inert. It can not give itself motion, nor can it change of itself the motion which it may have received.

The inertia of matter is illustrated by the *hydraulic cane*, which consists of a straight and open glass tube, having a metallic valve at one end. If this end be immersed in a vessel of water, and be slightly depressed by a sudden jerk, the valve, on account of its inertia, lags behind, and water passes by it into the tube. The valve immediately falls by its own weight, and prevents the water from returning. By a second jerk the valve is again opened, more water enters, and by a repetition of these movements the tube is entirely filled.

33. A body at rest will forever remain so unless disturbed by something without itself; or if it be in motion in any direction, it will continue to move in that direction, for there is no reason why it should deviate to one side more than another; and it will retain its velocity unaltered, since no reason can be assigned why it should be increased or diminished in the absence of all extraneous causes.

Whenever a moving body is reduced to a state of rest, some external force must have operated upon it. The chief causes of the loss of motion are friction, the resistance of the air, and gravitation.

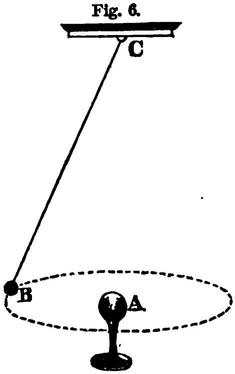
When a ball is rolled upon a horizontal table, its motion gradually diminishes until it stops. This result is to be ascribed to friction; for we find that, in proportion as the obstacles to motion are removed, the motion continues a much longer time.

A steam-boat requires a continued application of power to maintain it in uniform motion, on account of the great resistance it encounters.

34. There are some *apparent exceptions* to this law, but they are only apparent. An ivory ball, or a cylindrical ring, lying upon a table, may be so struck with the hand, that it shall proceed a few inches forward and then return. In this case, the blow of the hand not merely gives the ball an impulse forward, but imparts a rotary motion in the contrary direction. This rotary motion soon destroys the effect of the forward impulse, and causes the ball to change the direction of its motion.

35. The tendency of bodies to move in a straight line was denied by the ancients. Aristotle taught that the motion of the heavenly bodies was naturally *circular*. But, according to the Newtonian Philosophy, whenever we see a body revolving freely in a circle, we are authorized to infer that it is acted upon by two forces, one of which alone would cause motion in a straight line, while the other continually draws it out of this line toward the centre.

Fig. 6.



This principle is illustrated by a weight, B, suspended by a string from a fixed point, C. If the weight be deviated from the vertical position, and a slight lateral impulse be given to it, it will revolve in an orbit about the position of rest; and the impulse may be so regulated as to make the orbit sensibly circular. Of the two forces here acting upon the body, one is the original impulse, which of itself tends to impart motion in a straight line, and the other is the force of grav-

ity, which continually draws the body toward the position of rest.

36. LAW II.—*Change of motion is proportional to the force impressed, and is in the direction of the line in which that force acts.*

If any force generates a certain motion, a double force will generate double the motion.

This law is confirmed by all experience.

This principle is sometimes misunderstood. Thus, if a certain force will impel a boat with a velocity of 10 miles per hour, it has been inferred that a double force would impel it 20 miles per hour. This conclusion, however, is not warranted by the second law of motion, because a portion of the force employed is expended in giving motion to the water, which must be displaced in order to permit the progress of the vessel.

37. LAW III.—*To every action there is always opposed an equal reaction.*

Thus, if we suspend a weight by a string from a hook, the hook pulls the weight as much as the weight pulls the hook.

When we strike a nail with a hammer, the hammer *receives* a blow exactly equal to that which it *gives*.

So when a ball falls toward the earth, the earth also falls toward the ball, and the *quantity* of motion in each is the same, the quantity of motion being estimated by the product of the quantity of matter into the velocity; but, since the earth is many million times heavier than a pound ball, the velocity with which the ball moves toward the earth will be many million times greater than that with which the earth moves to meet the ball.

This law applies to every species of action, whether it be pressure, collision, attraction, or repulsion.

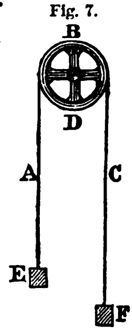
38. *Velocity of Motion.* The velocity of a moving body is expressed by stating the length of the path described by the body during a given time. We may employ various units of time and distance to express the velocity. In mechanical inquiries, it is common to employ a foot as the unit of space, and a second as the unit of time.

The velocity of a body in motion may be *uniform* or *variable.* The velocity is uniform when the body describes equal spaces in equal times. When the spaces described in equal times contin-

ually increase, the body is said to move with an *accelerated* velocity. When these spaces continually decrease, it moves with a *retarded* velocity.

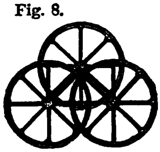
39. An *impulsive force* is one which acts but for an instant, and then ceases. Such a force causes a body to move with a uniform velocity. This may be shown with Atwood's machine —a machine specially contrived to demonstrate the laws of falling bodies.

Fig. 7.



In this machine, a fine thread, ABC, passes over a grooved wheel, D, having a horizontal axis, and supports at its extremities two equal weights, E and F. Now, since the earth's attraction upon one weight exactly balances the attraction upon the other, if we give one of them an impulse in a vertical direction, it will move as if it had no weight. We are thus able to observe the effect of a single impulse without the interference of any other force. To obviate the effect of friction on the axle of the wheel, each end is made to rest upon two friction-wheels, as shown in Fig. 8. A graduated scale of inches measures the space passed over, and a pendulum with the necessary clock-work measures the time of motion.

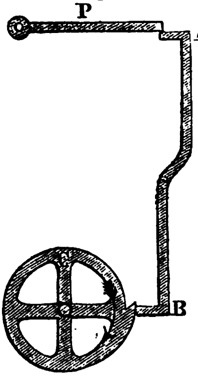
Fig. 8.



The required impulse is best given by a small bar added to one of the weights; and we place a brass ring, which will allow the weight to pass freely through it, but which may intercept the bar when it has communicated the desired velocity. After the bar is taken off, the weights, being now equal, are seen to move over equal spaces in equal times.

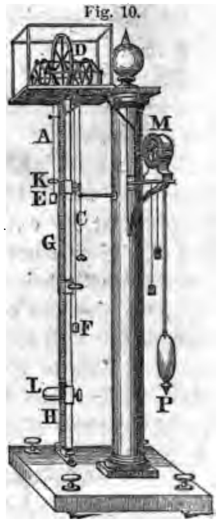
40. It is most convenient to have the motion commence exactly at the even minute, as indicated by the clock. This is effected in the following manner. The weight rests upon a small platform, P (*Fig.* 9), which is supported by the upper arm, A, of a lever, the lower arm of which, B, presses against a wheel, C, having a projecting shoulder. This wheel revolves once a minute; and when the index of the clock comes round to 60, this shoulder passes by the lower end of the lever, when the lever

Fig. 9.



falls inward from the effect of gravity; the upper arm is thrown outward, and liberates the platform, P, which supports the weight. The entire machine is represented in *Fig.* 10.

Fig. 10.



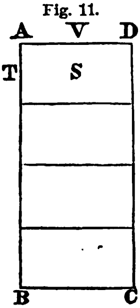
We will make each of the weights $31\frac{1}{2}$ ounces, and add to one of them a long bar weighing one ounce. We will place the ring at 12 inches on the vertical scale.

After the long weight is taken off, the descent in 1 second is found to be 12 inches;

"	2 seconds	"	"	24	"
"	3 "	"	"	36	"
"	4 "	"	"	48	"
"	5 "	"	"	60	"

41. From these experiments we find that the space described in five seconds is five times as great as that described in one second, and we conclude that *in uniform motion the space = time × velocity.* Hence the time $= \frac{\text{space}}{\text{velocity}}$, and velocity $= \frac{\text{space}}{\text{time}}$.

Fig. 11.



42. The space described by a body moving uniformly may be represented by a right-angled parallelogram, ABCD, one side of which, AB, represents the time, and the adjacent side, AD, the velocity; because the relation between the area of the rectangle and its two adjacent sides is the same as that between the space, time, and velocity of the moving body. This mode of representing, by means of a geometrical figure, the quantities treated of in Mechanics, has many important advantages, and is very extensively employed.

43. *The Force of Matter in Motion.*

A mass of matter in motion exerts force against any opposing object. This is true of solids, liquids, and gases.

The effect of a *solid mass* in motion is seen in the blows of a hammer, in the stroke of the die in coining metal, and in the destruction caused by a cannon ball.

The effect of a *liquid mass* in motion is seen in the waterfall impelling the wheel which does the work of a mill, and it is also seen in the torrent that sweeps away buildings.

The effect of *air* in motion is seen in the revolution of a windmill, in the progress of a ship over the sea, and in the destructive violence of the hurricane.

This force exerted by matter in motion is called *momentum*, and sometimes moving force, or *quantity of motion.*

44. The moving force of a body is proportional to its velocity. Thus the force with which a ball moving ten feet per second will strike an object, is ten times the force with which the same ball, moving one foot per second, will strike the object.

The moving force is also proportional to the mass moved.

Let M represent the momentum of a body, Q its quantity of matter, and V its velocity; then, $M = Q \times V$.

For example, if the quantity of matter in a body be 8 pounds, and its velocity 6 feet per second, then

$$\text{its momentum, } M = 8 \times 6 = 48;$$

which means that the momentum of the body in question is the same as that of a body weighing 48 pounds, and moving one foot per second.

Ex. 1. Suppose a battering-ram which weighs 5000 pounds is impelled with a velocity of 12 feet per second, with what velocity must a cannon ball weighing 32 pounds move in order to have the same momentum? *Ans.* 1875 feet per second.

Ex. 2. A ship weighing 500,000 pounds is dashed against the rocks, in a storm, with a velocity of 15 feet per second; with what momentum did she strike? *Ans.*

45. If we represent the quantity of matter in a second body by Q', and its velocity by V', and if $Q.V = Q'.V'$; then,

$$V : V' :: Q' : Q;$$

that is, *when two bodies have equal momenta, their velocities will be inversely as their quantities of matter.*

SECTION III.

COMPOSITION AND RESOLUTION OF FORCES, AND MOTION.

46. *Composition and Resolution of Forces.* The effect of a force depends upon,

1. Its *intensity* or quantity.
2. Its *direction.*
3. The point of the body to which it is applied, called *the point of application.*

47. It is customary to express the intensity of a force by an *equivalent weight.* Whatever be the nature of a force, a weight may always be named which will produce the same effect.

The intensities of forces may be represented by *straight lines.* If a given straight line, for example, *one inch* in length, be assumed to represent *the unit* of intensity, then a line two inches in length will represent a force of double intensity, a line three inches in length will represent a force of triple intensity, etc.

48. If *two or more forces* act upon the same point and in *the same direction,* their effect will be equivalent to a single force which is equal to *their sum.*

If a carriage be drawn by three horses, one pulling with a force of 300 pounds, the second with a force of 250, and the third with a force of 200 pounds, then the effect upon the carriage will be equal to the action of a single horse pulling with a force of $300+250+200$, that is, 750 pounds.

A single force which would produce the same effect as several forces acting together, is called the *resultant* of those forces. Thus, in the preceding example, the force of 750 pounds is the resultant of the three forces, 300 pounds, 250 pounds, and 200 pounds.

The several forces whose combined effect is equivalent to that of a single force are called the *components* of that force.

49. If two forces act upon a body *in opposite directions,* the smaller force will neutralize as much of the greater as is equal to itself, and there will be a resultant in the direction of the greater equal to *their difference.*

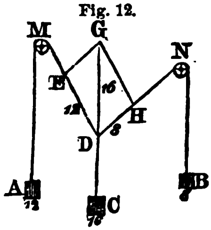
If a carriage be drawn forward with a force of 300 pounds,

and be pulled backward with a force of 100 pounds, an effective force of 200 pounds will remain in the forward direction.

In general, the resultant of two forces applied to the same point *in opposite directions*, is in the direction of the greater force, and is equal to *their difference*.

50. *If a point be kept at rest under the action of three forces, these forces may be represented in quantity and direction by the sides of a triangle formed by lines drawn in their respective directions.*

Fig. 12.



Let two weights, A and B, be attached to the extremities of a cord which passes over two pulleys, M and N, and let another cord be attached to this at some intermediate point, D, and let a third weight, C, be suspended from it. After some oscillations, the system will come to rest. The point D is now acted upon by *three forces;* 1st, by the weight A, acting in the direction of the line DM; 2d, by the weight B, acting in the direction DN, or its parallel, EG; and, 3d, by the weight C, acting in the direction of the line DC. Take DE equal to as many inches as there are ounces in A, and EG, parallel to DN, equal to as many inches as there are ounces in B; then DG will be found in the same line with CD, and will contain as many inches as there are ounces in C; that is, the three forces which act upon the point D are represented, in *quantity and direction*, by the sides of the triangle DEG.

For example, if the weight A be 12 ounces, B 8 ounces, and C 16 ounces, take DE equal to 12 inches, and EG, parallel to DH, equal to 8 inches; then DG, the third side of the triangle, will contain 16 inches, and will be in the same straight line with DC.

51. Conversely, we infer that *if three forces, acting upon the same point, are represented in quantity and direction by the sides of a triangle taken in order, the point will remain at rest.*

Now the weight C, acting in the direction DC, would be balanced by an equal force acting in the opposite direction, DG; and since the weight C is in equilibrium with the two weights A and B, which act in the directions DM and DN respectively, the resultant of the forces A and B must be a single force act-

ing in the direction DG; but DG is the diagonal of the parallelogram DEGH. Hence,

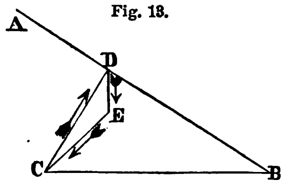
52. *If the adjacent sides of a parallelogram represent two component forces in quantity and direction, the diagonal will represent the resultant force in quantity and direction.*

This proposition is called the *Parallelogram of Forces.*

In all mechanical investigations, the resultant may be substituted for the components, or the components for the resultant, without changing the condition of the body on which these forces act.

53. *A kite* sustained in the air is an example of a body kept at rest under the action of three forces, these forces being the impulse of the *wind*, the *weight* of the kite, and the tension of the *string*.

Fig. 13.



Let AB represent the surface of the kite. Suppose the wind to blow horizontally, and let its force, as well as direction, be represented by the line CB. Draw CD perpendicular to the plane of the kite, and DB parallel to it. CB may be considered as the resultant of the two forces CD and DB; that is, we may consider the actual wind to be represented by two different winds, one blowing perpendicularly to the surface of the kite, while the other strikes the kite edgewise, and produces no effect upon it. The only part of the wind which is effectual to sustain the kite is then CD. Draw DE in a vertical direction, and let it represent the weight of the kite, and let CE represent the tension of the string. If these three forces are represented in quantity and direction by the three sides of the triangle CDE, the kite will remain at rest.

54. *The resultant of any number of forces,* acting upon the same point of a body, may be found in the following manner:

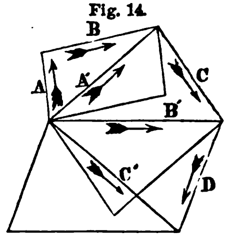
Represent the several forces by A, B, C, D, etc.

1st. Find the resultant of A and B, according to the principles already explained, and represent this resultant by A′.

2d. Find the resultant of A′ and C in the same manner, and let this resultant be B′.

3d. Find the resultant of B′ and D, and let this resultant be C′.

Fig. 14.



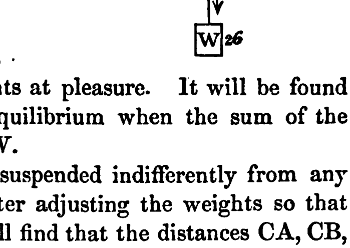
By proceeding in this manner, we shall finally arrive at a single force, which will be the resultant of the entire system. This resultant will be represented by *the last side of a polygon formed by lines drawn in the direction of the forces.*

We thus see that *any number of forces*, acting upon the same point, may be reduced to a single force, or *resultant*; and, conversely, a single force acting upon a point may be resolved into any number of forces, acting upon the same point, and producing the same effect as the single force.

55. Hence, also, we conclude, that *if any number of forces acting upon the same point be represented in quantity and direction by the sides of a polygon taken in order, the point will remain at rest.*

56. *The resultant of two forces which act on different points of the same body, in parallel lines and in the same direction, is a single force parallel to their direction and equal to their sum.*

Fig. 15.



Let A and B be the points to which the two forces are applied, and let two weights, P and P′, be attached to the parallel cords AM and BM′, going over the pulleys M, M′. Let a weight, W, be suspended from a point, C, between A and B. Instead of fixed weights at P and P′, we will employ scales capable of receiving any weights at pleasure. It will be found that there can only be an equilibrium when the sum of the weights P and P′ is equal to W.

The weight W can not be suspended indifferently from any point of the line AB; and after adjusting the weights so that there is an equilibrium, we shall find that the distances CA, CB, are inversely proportional to the weights P and P′. Hence,

57. *The resultant of two parallel components divides the line joining their points of application, into parts reciprocally proportional to the intensities of the components.*

For example, if the weight P be 8 ounces, and P′ 18 ounces, then, in order to balance them, the weight W must be equal to 26 ounces; and if the line AB be 26 inches long, then the distance BC must be 8 inches, and AC 18 inches. If the line AB be supposed to have weight, then it must be previously counterpoised by suitable weights in the scales P and P′. The preceding proposition may then be verified experimentally, precisely as if the bar AB had no weight.

Example.—Two parallel forces acting in the same direction have the magnitudes 5 and 16, and their points of application are 7 feet distant. What is the magnitude of their resultant, and its distance from each point of application?

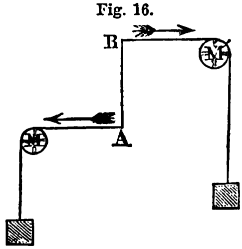
Ans. The resultant is 21, and its distance from the force 16 is 20 inches.

If the forces P and W are considered as components, the force P′ will be equal to their resultant, but acting in the contrary direction; that is, *the resultant of two parallel components is equal to the difference of the components when they act in opposite directions.*

58. *When two equal forces act upon two points of a body in parallel and opposite directions, they produce no progressive motion, but cause the body to revolve round a point intermediate between the points of application of the two forces.*

Such a system of forces is called a *couple.*

Fig. 16.



Let A and B be the points of application of the two forces, and let one of the forces act in the direction AM, while the other acts in the direction BM′; these forces tend to turn the line AB round in the direction of the motion of the hands of a clock. This tendency can not be counteracted by any single force, but may be resisted by another couple applied to two other points of the same body, and acting in a direction contrary to the former couple.

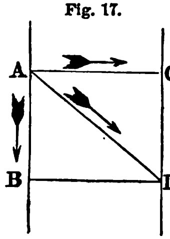
59. *Composition and Resolution of Motion.*

Since forces which produce pressure would (if the bodies on which they act were free to move) produce motion in the direction of this pressure, whose velocity would be proportional to the

pressure, the principles which have been established respecting the composition of forces are equally applicable to motion; that is,

If a body receive at the same time two impulses, one of which would cause it to move over one side of a parallelogram, and the other over the adjacent side of the parallelogram in the same time, the two impulses, acting simultaneously, would cause it to move over the diagonal of the parallelogram in the same time.

Fig. 17.

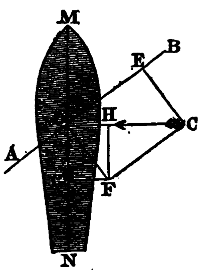


Let AB, CD, represent the banks of a river. If there be no current, a boat rowed in the direction AC will reach the opposite bank at C; but if there is a current which in the same time would carry a boat to B, then the boat will reach the opposite bank at D, and the boat will have described the line AD, which is the diagonal of a parallelogram constructed upon the lines AB, AC.

60. *The flying of a bird* affords an illustration of the same principle. The bird beats the air with two wings in directions inclined to each other, and it moves in the direction of the resultant of those forces.

So also *the rowing of a boat*, the act of swimming, and the motions of fishes are examples of the composition of forces.

Fig. 18.



61. By means of the resolution of forces, we may estimate the effect of a wind to propel a vessel on the ocean. Thus, let AB represent the sail of a ship, MN, and suppose the wind to blow in the direction CD, oblique to the sail, its force being represented by the line CD. Draw CE perpendicular to the sail, and CF parallel to it. CD may be considered as the resultant of the two forces CE and CF; that is, we may consider the actual wind to be represented by two different winds, one blowing perpendicularly to the surface of the sail, while the other strikes the sail edgewise, and produces no effect upon it. Hence the effective part of the wind, CD, is represented by FD.

But this force FD still acts obliquely to the keel.

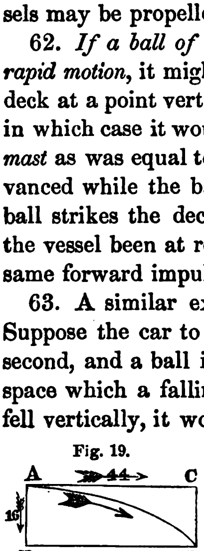
Draw FG perpendicular to the keel, and FH parallel to it. The forcė, FD, of the wind upon the sail may be replaced by two different winds, one in the direction of the keel, and the other perpendicular to it. The original forcė of the wind CD will thus be represented by three distinct winds; one, ED, striking the sail edgewise; another, DH, at right angles to the keel, and producing lee-way; and the third, GD, acting in the direction of the keel, and serving to propel the vessel.

A wind which blows in a direction *perpendicular* to the course of the vessel may thus be made to *propel the vessel*, and two vessels may be propelled *in contrary directions by the same wind.*

62. *If a ball of lead be let fall from the topmast of a vessel in rapid motion*, it might be supposed that the ball would strike the deck at a point vertically under that from which it began to fall; in which case it would strike the deck at a point as far *behind the mast* as was equal to the space through which the vessel had advanced while the ball was falling. We find, however, that the ball strikes the deck precisely where it would have struck had the vessel been at rest, because the ball, when it started, had the same forward impulse as the vessel.

63. A similar experiment may be tried upon a railway-car. Suppose the car to be moving 30 miles per hour, or 44 feet per second, and a ball is dropped from it at the height of 16 feet, a space which a falling body describes in one second. If the ball fell vertically, it would strike the ground at a point 44 feet behind the point of the carriage from which it was dropped, for the car would be 44 feet in advance of the point at which the ball was let fall; but we find that the ball meets the ground at a point vertically under that part of the car from which it fell, showing that, during the fall, the ball advances with the same progressive motion as the car. If AC represent the space described by the car in one second, and AB the space described by a body, falling from rest, in one second, then the actual path of the ball will be represented by the line AD.

Fig. 19.



SECTION IV.

CENTRE OF GRAVITY.

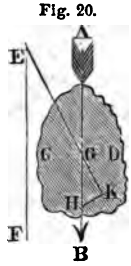
64. *Each atom* which composes a body has *weight*, and the weight of the mass is the sum of the weights of all its atoms.

If the particles composing a body had no mutual cohesion, each particle would obey the force of gravity independently of the others; but, being connected by cohesion, the several forces acting upon the particles are compounded so as to produce a single force, which is *the resultant* of all these separate forces.

This resultant is a force acting vertically downward, and equal to the sum of all the forces affecting the particles severally.

65. When we know the form and dimensions of a body, we can *compute* the exact position of this resultant; but its position is more easily determined by *experiment*.

Fig. 20.



Suppose AB to be the resultant of the weights of all the particles of the body CD; then it is evident that if any point, as A in that line, be supported (as, for example, by means of a thread suspended from a hook), the body will remain at rest. But if the body be suspended from a point, E, which is not in the direction of the resultant AB, the body will *not* remain at rest. Let the line GH represent the weight of the body, and draw HK perpendicular to EK. Then GK will represent that portion of the weight which acts in the direction of the string, and produces pressure upon E, while HK represents that portion of the weight which acts in a direction perpendicular to the string, and tends to move the body in the direction KH toward EF; that is, *if a body be suspended from a fixed point, it will not remain at rest unless the resultant of the weights of all its particles passes through that point.*

66. Hence, if we suspend a body by a string, and allow it to come to rest, the resultant of the weights of all its particles will be in the direction of the string.

If the same body be suspended successively from *a number of different points*, the resultant of the weights of the particles of the

body will be found to have as many different positions, but all these resultants *will intersect each other in a common point.* This result may be easily verified by taking a solid body of some material which is easily perforated.

The experiment is most conveniently performed with a flat, thin plate of metal or some other solid substance.

This common point, through which the resultant of the gravity of the particles always passes, is called their *centre of gravity.*

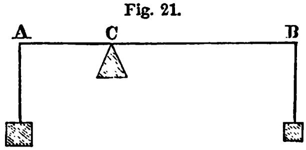
67. A line drawn vertically through the centre of gravity of a body is called *the line of direction* of the centre of gravity.

If the centre of gravity of a body be supported on a point, and the body be free to turn round, the body will remain at rest in any position in which it may be placed; for the resultant of the weights of all its particles is in the direction of a vertical line passing through the centre of gravity, and this resultant will be supported when the centre of gravity is supported.

Hence *we may define the centre of gravity of a body to be that point about which, if supported, all the parts of the body* (acted upon only by the force of gravity) *balance each other in any position.*

68. *The common centre of gravity of two bodies* may be found from the following principle, which results from the theory of parallel forces, already explained on page 31.

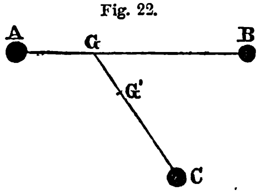
Fig. 21.



Two weights, A *and* B, *acting at the extremities of an inflexible rod, will be in equilibrium about a given point,* C, *when their distances from that point are inversely as those weights.* This point of support is the centre of gravity of the two weights.

For example, if the weight A be 20 ounces, and B 10 ounces, and if the length of the arm AC is 7 inches, then, in order that the two weights may be in equilibrium, BC must be 14 inches.

Fig. 22.



69. *To find the centre of gravity of three bodies,* A, B, *and* C, we first find G, the centre of gravity of two of them, A and B, according to the principle just stated. Then, regarding these two as a single body united in G, we find G′, the centre of gravity of

this and the third body, C; and in the same manner we may proceed for any number of bodies.

70. It is evident that *the centre of gravity of a straight line is at its middle point,* for each particle on one half of the line is balanced by a corresponding particle on the other side.

Also, *if a body of uniform density have any regular figure, such as a square, regular polygon, circle, etc., its centre of gravity will coincide with its centre of magnitude.*

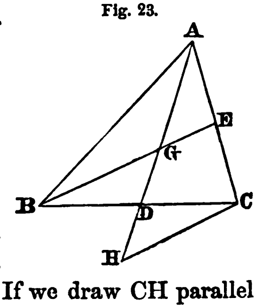
So, also, the centre of gravity of a cube or a sphere of uniform density, is at the centre of magnitude.

If the figure of a body be such that the matter composing it is distributed *symmetrically* round any line passing through it, its centre of gravity must lie in that line, as the diameter of a circle, the axis of an ellipse or parabola.

So, also, the centre of gravity of a cone of uniform density must be in its axis. The centre of gravity of a cylinder will be at the middle point of its axis.

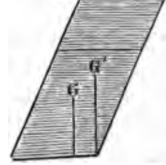
71. *The centre of gravity of a triangle,* ABC, *is in the line which joins the vertex,* A, *with the middle of the base,* BC, *and at a distance from the base equal to one third the length of the bisecting line.*

Fig. 23.



If we draw AD to the middle of the base BC, it is plain that the centre of gravity must be in the line AD; for we may consider the triangle as composed of lines of particles parallel to BC, and each of these lines will be bisected by AD. Also, if we draw BE to the middle of the line AC, the centre of gravity, for the same reason, must be in the line BE. It must therefore be at G, the point of intersection of the two lines. If we draw CH parallel to BE, since AE=EC, AG must be equal to GH. But the triangle BDG is equal to the triangle CDH; therefore DG=DH, and GD=⅓AD.

Fig. 24.



72. *Properties of the Centre of Gravity.*

A body will rest upon a horizontal plane, only when the line of direction of the centre of gravity falls within the base. Some buildings incline very much from the vertical position, but do not

fall, because the line of direction is kept within the base. The leaning tower of Pisa is 179 feet in height, and overhangs its base 13 feet. The leaning tower of Bologna is 134 feet high, and overhangs its base 9 feet.

73. In the case of animals, also, the line of direction must be kept within the base, or the body will fall. The base of the human body may be regarded as the space covered by the feet and the area between them.

When a man carries a load in one hand, the centre of gravity of the system is moved to that side; and in order to keep the line of direction within the base, the man inclines his body in the opposite direction.

If a man bears the load upon his back, he must bend forward; if he carries the load in front, he must incline backward.

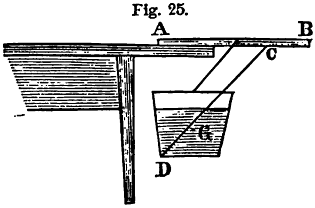
A person sitting on a chair can not rise from it without inclining forward to bring the centre of gravity over the feet, or drawing back the feet to bring them under the centre of gravity.

If a person stand with his side close against a wall, his feet being close together, he can not raise the outside foot; for if he did, the line of direction of the centre of gravity of his body would be unsupported.

74. A prop which supports the centre of gravity of a body supports the whole body. The following paradox is founded upon this principle.

"*A body, having a tendency to fall by its own weight, is sustained by adding a weight on the same side on which it tends to fall.*"

Fig. 25.

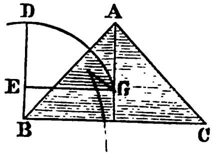


This is effected as follows: Lay the end of a stick, AB, on the top of a table; suspend a pail of water from it, and place a second stick, CD, with one end resting against the corner of the pail, and the other against the first stick. By this arrangement, the centre of gravity of the system, G, is moved so as to fall vertically under the edge of the table.

A spinning-top, when in rapid rotation, stands upon its point although the line of direction falls without the base. The reason of this will be explained on page 103.

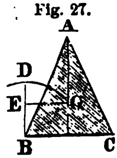
75. *The stability of a body* is estimated by the magnitude of the force required to overturn it, and depends upon the distance of the line of direction of its centre of gravity from the edge of its base.

Fig. 26.



Let ABC represent a pyramid, whose centre of gravity is at G. In order to turn this over the edge, B, the centre of gravity must be carried over the arc GD, of which B is the centre, and must therefore be lifted through the height DE.

Fig. 27.



If, however, the base of the pyramid was less in comparison with its height, the space DE, through which the centre of gravity must be elevated, would be less, and a smaller force would throw the pyramid over the edge B.

If the line of direction of the centre of gravity fall precisely upon the edge B, the body may still stand, but the slightest force will be sufficient to overturn it.

The centre of gravity of a loaded wagon should therefore be *as low as possible;* for, when it is high, a little inequality in the road may throw the line of direction without the base.

76. There are *three different positions* in which the centre of gravity may be supported.

First, The prop may be applied directly to *the centre itself;* in which case the body will rest *in any position,* as in a common wheel. This is called a case of *indifferent equilibrium.*

The centre of gravity of a body may be far from the centre of figure. It may even be without the body itself, as in a hoop; yet even in this case the centre of gravity possesses the same properties as when it is included within the mass of the body.

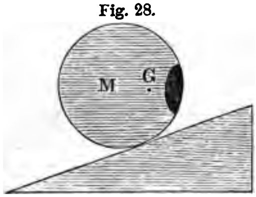
77. *Second,* The point of support may be *above the centre of gravity;* in which case, if we deviate the body from this position, it will always tend to return to it; and it will not rest until the centre of gravity is vertically under the point of support. This is called a case of *stable equilibrium.* It is seen in a weight suspended by a thread from a hook.

This is the principle of the trick sometimes proposed—"to hold a pointed stick upright on the tip of the finger without its being able to fall." It is accomplished by affixing two knives

to the stick, so as to bring the centre of gravity of the system below the point of support.

78. *A body which is free to move can not be in a position of permanent equilibrium, unless the centre of gravity is at the lowest point.*

Fig. 28.

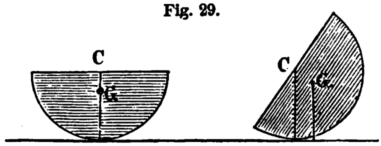


This principle often gives rise to motions which are apparently contrary to gravity. The cylinder M, loaded on one side so as to have its centre of gravity at G, will roll up an inclined plane until the centre of gravity has reached the lowest position. In this case, although *the centre of magnitude rises*, the point occupied by *the centre of gravity falls.*

A ball loaded on one side will rest only when the loaded side is downward.

A witch is the name given to a figure made of paper or plaster, except the bottom, which is of metal, and in shape nearly a hemisphere. It will only rest when the metallic base is in the lowest position; that is, when the figure is upright.

Fig. 29.



79. *A hemisphere upon a horizontal plane will rest only when its base is horizontal.* The hemisphere always touches the plane in the point vertically under the centre, C. When the centre of gravity, G, is not in this vertical line, the line of direction is not supported, and the centre of gravity falls. The centre of gravity reaches the lowest point when the base of the hemisphere is horizontal.

80. *Third,* The point of support may be *beneath the centre of gravity.* In this case, if the centre of gravity be in the least removed from the vertical position, instead of returning to it again, it describes an entire semicircle, and, after a series of oscillations, comes to rest vertically below the point of support. This is called a case of *unstable equilibrium.*

SECTION V.

THEORY OF MACHINERY.

81. *A machine* is an instrument by which a force applied at a certain point, is made to exert a force at another point more or less distant from the former, and generally different in intensity and direction.

Thus the momentum of water acting against the float-boards of a wheel, turns a water-wheel which does the work of a cotton factory.

The force which is employed in working a machine is called *the power;* the point at which it is applied is called *the point of application; its direction* is the line in which the force tends to make the point of application move; and *its intensity* is usually expressed by a weight, which, acting at the same point, would produce a like effect.

The moving power may be *human strength, animal force, wind, water*, or *steam.*

That part of a machine which is immediately applied to the resistance to be overcome is called *the working point.*

82. The resistance to which the working point is applied is called *the weight* or *load.*

This resistance may consist chiefly of the weight of matter, as in raising water from a well or ore from a mine; or it may be simple friction, as in moving a train of cars upon a level railway.

The resistance is expressed by the weight which would produce an equivalent force acting against the moving power.

In explaining the theory of machinery, we omit, in the first instance, many circumstances of which account must subsequently be taken. The parts of a machine are considered to move without friction; ropes and chains are supposed to have neither stiffness, thickness, nor weight; the machine is supposed to encounter no resistance from the air, and to have neither weight nor inertia. These circumstances, which are at first neglected, are afterward taken into account.

83. Machines which consist of but one part are called *simple machines.*

Those which are composed of two or more parts, acting one upon another, are called *complex machines*.

The effect of complex machines is determined by combining together the separate effects of the simple machines of which they are composed.

Simple machines have generally been divided into six classes:

1. The Lever.
2. The Wheel and Axle.
3. The Pulley.
4. The Inclined Plane.
5. The Screw.
6. The Wedge.

84. THE LEVER.

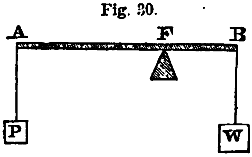
A lever is an inflexible bar, supported on a point, about which it moves freely.

The point of support is called *the fulcrum* or *prop*.

Generally, the lever is a *straight bar*; sometimes the two arms make *a right angle* with each other; and they may be inclined to each other *at any angle*.

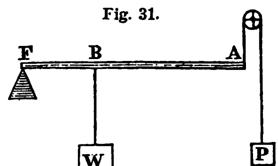
Levers are commonly divided into *three classes*.

Fig. 30.



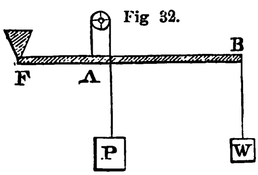
In a lever of *the first kind*, the fulcrum is between the power and the weight, as shown in *Fig*. 30.

Fig. 31.



In a lever of *the second kind*, the weight is between the power and the fulcrum, as shown in *Fig*. 31.

Fig 32.



In a lever of *the third kind*, the power is between the weight and the fulcrum, as shown in *Fig*. 32.

85. According to what has been shown on page 36, in treating of the centre of gravity, there is an equilibrium between the power and weight in a lever of the first kind, when *the power and weight are to each other inversely as their distances from the fulcrum*; that is,

$$P : W :: BF : AF, \text{ or}$$
$$P \times AF = W \times BF.$$

Experiment.—With a lever of the first kind, a power of 16 ounces acting on an arm 5 inches long, balances a weight of 5 ounces acting on an arm 16 inches long.

86. The effect of the power to turn the lever round its fulcrum is measured by $P \times AF$, which may be called the *momentum of the power;* and the effect of the weight to turn the lever round its fulcrum is measured by $W \times BF$. Hence, when there is an equilibrium, *the power and weight have equal momenta.*

If we increase the amount of the power, P, or increase its distance from the fulcrum, the efficiency of the power to turn the lever will be increased in the same ratio.

87. In a lever of the second or third kind, the conditions of equilibrium are the same as in one of the first kind; that is, *the power and weight must be to each other inversely as their distances from the fulcrum;* for the effect of the power, P, to turn the lever about the fulcrum is measured by $P \times AF$, and the effect of the weight, W, to turn the lever about the fulcrum is measured by $W \times BF$. But when there is an equilibrium, these opposite tendencies must be equal; hence,

$$P \times AF = W \times BF; \text{ or,}$$
$$P : W :: AF : BF.$$

Experiment 1.—With a lever of the second kind, a power of 6 ounces acting on an arm 30 inches long, balances a weight of 18 ounces acting on an arm 10 inches long.

Experiment 2.—With a lever of the third kind, a power of 20 ounces acting on an arm 4 inches long, balances a weight of 4 ounces acting on an arm 20 inches long.

88. We have an example of a lever of the first kind, when one end of a bar is placed under a block of stone, and the weight of a man is applied to the other end of the bar, the fulcrum being another stone placed near that which is to be raised. We have an example of a double lever of this kind in a pair of pincers used for holding or cutting.

We have an example of a lever of the second kind, when a bar is used to lift a heavy stone by raising one end of the bar with the hand, while the other end rests on the ground, and the stone is raised by an intermediate part of the bar.

A door when moved upon its hinges by a hand applied near the latch, is another example of a lever of the second kind.

Nut-crackers are composed of two levers of the second kind.

A door when moved upon its hinges by a hand applied near the hinge, is an example of a lever of the third kind.

We have an example of a double lever of the third kind in a pair of tongs used to hold a coal.

89. Ex. 1. In a lever of the first kind, 4 feet in length, the power is 10 pounds and the weight is 14 pounds. What must be their respective distances from the fulcrum when there is an equilibrium? *Ans.* 20 inches and 28 inches.

Ex. 2. A lever of the second kind is 5 feet long. At what distance from the fulcrum must a weight of 50 pounds be placed, so that it may be sustained by a power of 40 pounds?

Ans. 4 feet.

In a lever of the first kind, the power and weight may be *equal*, or *either may exceed the other*, according to their distances from the fulcrum.

In a lever of the second kind, *the power* is farther from the fulcrum than the weight, and is therefore *less* than the weight.

In a lever of the third kind, *the weight* is farther from the fulcrum than the power, and is therefore *less* than the power.

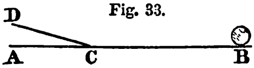
90. We find each of the varieties of lever applied in the *mechanism of the human body.*

An example of a lever of the *first kind* is seen in the head moving backward and forward on the vertebral column as a fulcrum, the power being exerted by the contraction of the muscles of the neck.

When the weight of the body is supported upon the toes, we have a lever of the *second kind:* The foot is the lever, the toes are the fulcrum, and the power is applied at the heel by a tendon which is attached to the muscles of the leg. The weight of the body is supported between the power and the fulcrum.

When we support a weight in the hand extended horizontally, we employ a lever of the *third kind.* The forearm, AB, is the lever, the elbow, A, is the fulcrum, the weight is at B, the extreme end of the lever, and the power is the force of the muscle, which, coming from the upper arm, is inserted into

Fig. 33.

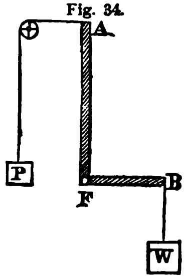


the forearm at C, near the fulcrum, while its direction, CD, makes a very small angle with the lever.

This power acts at *a great mechanical disadvantage*, requiring nearly 100 pounds in the muscle to lift one pound in the hand. But what is *lost in force is gained in velocity*. A slight contraction of the muscle moves the hand through a great distance. This rapidity of movement is more serviceable to man than mere strength.

91. In *the rectangular lever*, the arms are perpendicular to each other, and the fulcrum is at the right angle.

Fig. 34.



The momentum of the power is expressed by $P \times AF$, and that of the weight is $W \times BF$. When the power and weight are in equilibrium, *these momenta must be equal.*

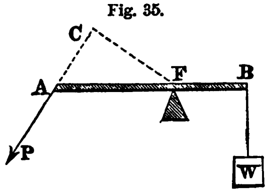
Experiment.—A power of 5 ounces on an arm 21 inches long, balances a weight of 15 ounces on an arm 7 inches long.

When a hammer is used for drawing a nail, it affords an example of the rectangular lever.

92. *When the two arms of a lever make any angle with each other*, the power and weight are to each other inversely as their distances from the fulcrum, provided the power and weight act *perpendicularly* to their respective arms.

If the forces applied to a lever do not act perpendicularly to the arms, their effect will be found by drawing from the fulcrum *perpendiculars* to the lines of direction in which the forces act.

Fig. 35.



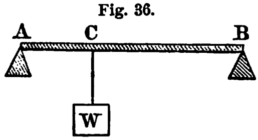
If the power act in the direction AP, draw FC perpendicular to the line PAC. The power will have the same effect in turning the lever as if it acted at C upon the lever CF. The momentum of the power will be equal to $P \times CF$, and, when there is an equilibrium, $P \times CF = W \times BF$.

93. *In a lever of whatever form, the power and weight must be to each other inversely as the perpendiculars let fall from the fulcrum upon the lines of direction in which the forces act.*

Experiment.—With a crooked lever, a power of 12 ounces

acting on an arm 6 inches long, balances a weight of 4 ounces acting on an arm of 18 inches; the perpendiculars drawn from the fulcrum upon the directions of the forces being regarded as the true lengths of the arms.

Fig. 36.



94. *When a beam rests on two props, and supports a weight at some intermediate point*, the prop B may be considered as a power sustaining the weight, W, by means of the lever BA. Hence we must have $B \times BA = W \times CA$. For the same reason, we must have $A \times AB = W \times CB$. Forming a proportion from these equations, and rejecting common factors, we find

$$A : B :: BC : AC;$$

that is, *the part sustained by each prop is inversely as its distance from the weight.*

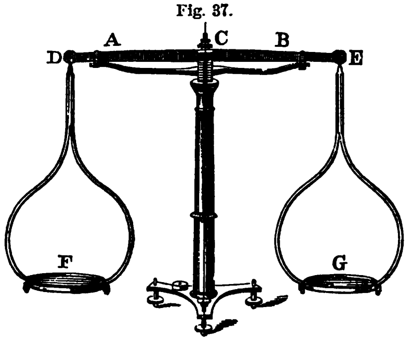
Thus, if AC is one third of AB, the pressure on A will be two thirds of the entire weight.

Example.—Two persons, A and B, sustain upon their shoulders a weight of 240 pounds by means of a pole 6 feet long, the point of suspension being $2\frac{1}{2}$ feet from A. What portion of the weight does each sustain? *Ans.* A 140 pounds, and B 100 pounds.

95. THE BALANCE.

A balance is a lever of the first kind with equal arms. The most important parts to be attended to in the construction of a balance are the *beam*, AB, the *fulcrum*, C, and the *points of suspension*, D and E.

Fig. 37.



The *sensibility* of the balance is increased by increasing the length of the arms; but, if the arms are *too long*, they are liable to *bend*, and their weight increases the *friction* on the support. In delicate balances designed for small weights, the beam seldom exceeds nine inches.

The *fulcrum* is made of hardened steel, in the shape of a triangular prism, and it rests on a plate of steel or agate.

96. The *centre of gravity* of the beam should be *a little below* the centre of motion.

If it *coincided* with the centre of motion, the beam would rest indifferently in any position, when the weights were equal, whereas we wish it to come to rest in the horizontal position.

If the centre of gravity were *above* the centre of motion, the smallest inequality of the weights would upset the beam.

If the centre of gravity were *far below* the centre of motion, the equilibrium would be too stable, and a slight difference between the two weights could not be detected.

The *sensibility* of the balance increases as the centre of gravity approaches the centre of motion.

A straight line joining the points of suspension should pass through the centre of motion; for when weights are added to the scales, the effect is the same as if the weights were concentrated in the points of suspension.

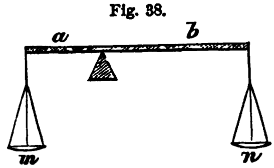
The *sensibility* of the balance is *estimated* by the fraction of the whole weight which it requires to turn the scales when loaded.

If, when loaded with 1000 grains, the beam turns with one grain, its sensibility is $\frac{1}{1000}$.

A balance constructed by Ramsden for the Royal Society of London turned with the $\frac{1}{10,000,000}$ part of the weight.*

97. The *false balance* is a lever with unequal arms, and is often used to defraud. The dishonest dealer, when buying, puts his merchandise in the shorter arm; when selling, he puts it in the longer arm.

Fig. 38.



The true weight may, however, be found in the following manner. Let x equal the true weight, and suppose, when the body is suspended from the arm a, it is balanced by the weight n; and when it is suspended from the arm b, it is balanced by the weight m. Then, from the principles of the lever, *Art.* 85, we shall have

* Young's Natural Philosophy, vol. i., p. 125.

$$x : m :: a : b,$$

and $$x : n :: b : a.$$

Whence $$x^2 : mn :: ab : ab;$$

that is, $$x^2 = mn, \text{ or } x = \sqrt{mn}.$$

Hence, *the true weight may be found by weighing the article first in one scale, then in the other, and taking a mean proportional between the two weights.*

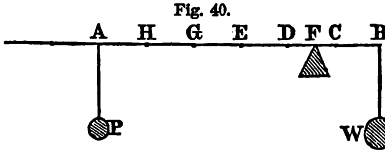
Thus, if the weight in one scale is 4 ounces, and 9 in the other, the true weight is not $\frac{4+9}{2}$, but $\sqrt{4 \times 9}$, or 6 ounces.

Or we may counterpoise an article with sand or shot, and then, removing the article, find the weight of the counterpoise. This is a very accurate method of weighing, and it is quite immaterial how great may be the inequality of the two arms.

Fig. 39.

98. The *bent lever balance* consists of a bent lever, ABC, one end of which, C, is loaded with a fixed weight, while the other supports a pan, E, to receive the merchandise. As the weight in the pan is increased, the other end of the lever is thrown outward, the effect of which is the same as if the lever were lengthened; for the weight in the scale E has to C the same ratio as BD to BK. The scale FG may be graduated by putting known weights into the scale-pan, and observing the corresponding positions of the arm C. The graduation of the scale will *not be into equal parts.*

Fig. 40.



99. The *steelyard* is a lever of the first kind with unequal arms, AF, BF; and a given weight, P, is movable along the longer arm, so as to sustain different weights suspended from the extremity of the shorter arm. It has usually two graduated sides, on one of which the weight W is placed nearer the fulcrum than on the other. Suppose the excess of the weight of the longer arm above that of the shorter is such that the weight P, when placed at C,

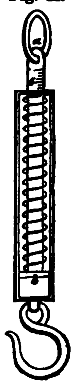
would keep the arms in equilibrium. Then the effect of W to turn the lever about the fulcrum is measured by $W \times BF$. The effect of P is measured by $P \times AF$; and the effect of the superior weight of the longer arm is measured by $P \times CF$. Hence, when there is an equilibrium,

$$W \times BF = P \times (AF + FC) = P \times AC;$$

and, since P and BF are constant quantities, W varies as AC. Therefore, if CD, DE, EG, etc., be taken equal to each other, and if P balances 1 pound when placed at D, it will balance 2 pounds at E, 3 pounds at G, etc.; that is, the arm AF is graduated into equal parts, commencing at C.

100. The *spring steelyard* depends on the elasticity of a spiral steel spring, *a b*. The amount of the weight suspended is shown by an index, which moves according as the spring is compressed. This is a very convenient instrument, but its accuracy is liable to be impaired by use.

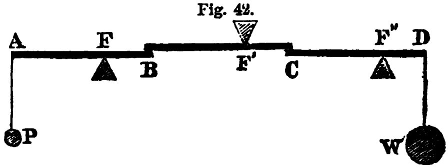
Fig. 41.



101. The *compound lever* is a combination of levers, in which one lever is made to act upon a second, the second upon a third, etc. The effect of such a combination may be estimated by considering the effect of each lever separately.

The power P (*Fig.* 42) : the effect produced at B :: BF : AF. Also, the force exerted at B : the force exerted at C :: CF′ : BF′, and so on for each of the other levers. Hence, by compounding these ratios, we find that when there is an equilibrium, *the power is to the weight, as the product of all the arms on the side of the weight, is to the product of all the arms on the side of the power.*

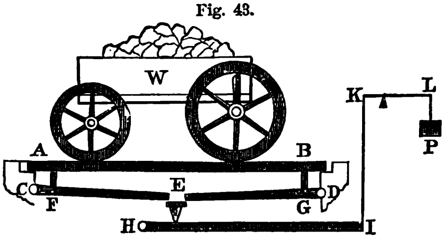
Fig. 42.



Experiment.—In a compound lever, of which the longer arms are 9, 12, and 15 inches, while the shorter arms are 3, 4, and 5 inches, a weight of 1 ounce balances a weight of 27 ounces.

The principle of the compound lever is applied in weighing heavy loads, as hay, cotton, coal, etc. Such a machine is rep-

Fig. 43.

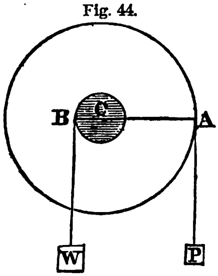


resented in *Fig.* 43. In this machine, a power, P, of 10 pounds, by the intervention of a system of levers, is often made to balance a load, W, of 10,000 pounds.

102. THE WHEEL AND AXLE.

The *wheel and axle* consists of a wheel having a cylindrical axis passing through its centre, and resting on pivots. The power is applied to the circumference of the wheel by means of a rope; the weight acts by means of a rope coiled round the axle.

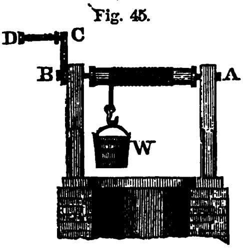
Fig. 44.



This machine acts as *a lever of the first kind*, the fulcrum being at C, the centre of the axle, the levers being BC and AC, the radii of the wheel and axle. The effect of the weight is measured by $W \times BC$; the effect of the power is measured by $P \times AC$. Hence the power and weight will be in equilibrium when $P : W :: BC : AC$; that is, *the power* : *the weight* :: *radius of the axle* : *the radius of the wheel.*

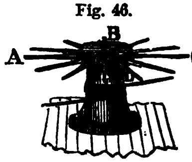
Experiment.—A weight of 1 ounce on a wheel 10 inches in diameter, balances 18 ounces on an axis $\frac{5}{9}$ of an inch in diameter.

Fig. 45.



103. Sometimes a *crank*, BC, is substituted for the wheel. It is then called a *windlass* if the motion is in *a vertical plane*. This arrangement is often employed for drawing water from a well, for turning a grindstone, etc.

Fig. 46.



If the motion take place in a *horizontal plane*, it is called a *capstan*, as ABCD. This is used on shipboard for weighing anchors, hoisting sails, etc.

The modes of applying the power to the wheel are various. Sometimes the circumference of the wheel is furnished with projecting pins, to which the hand is applied when human force is used; sometimes the wheel is turned by the weight of men or animals walking either upon the inner or outer circumference.

104. *The power of the wheel and axle may be increased* by increasing the diameter of the wheel or diminishing that of the axle. But there is a limit to the application of each of these principles. If the wheel be too large, it becomes unwieldy; if the axle be too small, it becomes too weak. These inconveniences are obviated by making the axle, AB, of two parts having different diameters, so that, while the rope winds round the thicker part of the axle B, it unwinds from the thinner part, A. To determine the ratio of the power to the weight in this case, let figure 48 represent a section of the apparatus at right angles to the axis. The weight is sustained by the two parts of the rope A and B, and therefore each part is stretched by a force equal to half the weight. The effect of the force which stretches the rope A, is half the weight $\times$ the radius of the thinner part of the axle; and the effect of the force which stretches the rope B, is half the weight $\times$ the radius of the thicker part of the axle; hence we must have P $\times$ the radius of the wheel $+$ half the weight $\times$ the radius of the thinner part of the axle $=$ half the weight $\times$ the radius of the thicker part of the axle; or P $\times$ the radius of the wheel $=$ the weight $\times$ half the difference of the radii of the two parts of the axle; that is, there will be an equilibrium between the power and weight, when *the power* : *the weight* :: *half the difference of the radii of the two parts of the axle* : *the radius of the wheel.* By making the two parts of the axle nearly of the same size, its power may be increased indefinitely. This apparatus is called *the differential wheel and axle.*

Fig. 47.

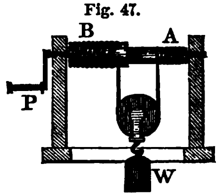
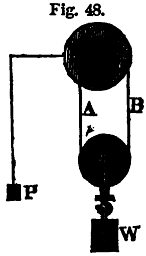


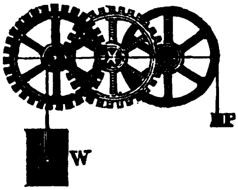
Fig. 48.



105. Wheels and axles commonly act upon each other by the aid of cogs, as in clock-work and mill machinery. The cogs on

the circumference of the wheel are called *teeth;* those on the axle are called *leaves;* and the axle itself is called a *pinion.*

Fig. 49.



The effect of a combination of wheels and pinions is similar to that of a system of compound levers. Hence, *in a system of wheels and pinions,* there will be an equilibrium between the power and weight when *the power* : *the weight* :: *the product of the radii of all the axles or pinions* : *the product of the radii of all the wheels.*

Since the number of teeth is generally proportional to the diameter of the wheels, *the power* : *the weight* :: *the product of the numbers denoting the leaves in the pinions* : *the product of the numbers denoting the teeth in the wheels.*

Experiment.—In a combination of three wheels and axles, the diameters of the wheels being 4 times those of the axles, a power of 1 ounce balances a weight of 64 ounces.

106. Wheels and axles may be *connected* in various ways. Motion may be transmitted from one wheel to another by means of a band or cord, as in the spinning-wheel and turning-lathe. The two wheels will turn in *the same direction* if the band does not cross itself. If the band crosses itself, they will turn in *opposite directions.*

Wheel-work serves to *regulate the velocity of motion.* Thus, in a watch, one hand makes one revolution in a minute, another in an hour, and a third in 12 hours, though all are impelled by the same power.

Example 1.—A power of 14 pounds acts on a wheel 9 feet in diameter. What weight, acting on an axle 7 inches in diameter, will keep it in equilibrium?

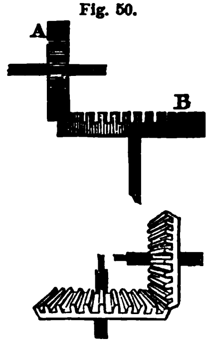
$$\textit{Ans.}\ \frac{14.9.12}{7} = 216 \text{ pounds.}$$

Example 2.—In a differential wheel and axle, the diameter of the wheel is 3 feet, the diameter of the thicker part of the axle 7 inches, and that of the thinner part $6\frac{1}{4}$ inches. What weight will a power of 60 pounds sustain?

$$\textit{Ans.}\ 60 : \text{W} :: \tfrac{3}{8} : 36 :: 1 : 96 \therefore \text{W} = 5760 \text{ pounds.}$$

107. Toothed wheels are of three kinds, *spur, crown,* and *beveled.*

Fig. 50.



A *spur* wheel is one in which the teeth are in the direction of *radii* from its centre, as A, *Fig.* 50.

A *crown* wheel is one in which the teeth are *perpendicular* to the plane of the wheel, as B, *Fig.* 50.

A *beveled* wheel is one in which the teeth are *oblique* to the axis of the wheel.

By combining these different forms of wheels, the resulting motion can be transferred to any required plane.

If a motion round one axis is to be communicated to another axis *parallel* to it, *spur wheels* are generally used.

If a motion round one axis is to be communicated to another at *right angles* to it, it may be effected by a *crown wheel* working on a *spur pinion;* or the same object may be attained by *two beveled wheels.*

If a motion round one axis is to be communicated to another inclined to it at any proposed angle, it may be effected by the use of two beveled wheels.

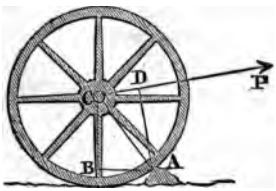
108. The teeth of wheels should have such *a form* as not to cause *rubbing* or *jarring.* If the teeth have sharp angles, the corner of one tooth grinds upon another, so that it is rapidly worn out. In order to diminish the friction, the teeth should roll upon one another without sliding. This may be accomplished by making the teeth of the form of the evolute of a circle.

109. Wheels, when applied to carriages, serve *two purposes.*

I. They diminish *the friction* on the ground, by transferring the friction from the circumference of the wheel to the axle. The advantage gained from this cause is in the ratio of the radius of the axle to that of the wheel; that is, the larger the wheel, and the smaller the axle, the less is the friction.

II. They serve to *raise the carriage* more easily *over obstacles* and asperities of the road. The advantage gained in this respect may be computed from the principles of the lever. Thus, let CP (*Fig.* 51) be the line of draught, and let A be an obstacle

Fig. 51.



to be surmounted. Draw AB in a horizontal direction, and AD perpendicular to CP. We may regard BAD as a bent lever, of which A is the fulcrum; the power is applied at D, and the weight at B. Hence, when there is an equilibrium, P : W :: AB : AD.

The effect of the power increases with the length of the arm AD. Hence *large wheels are best adapted for surmounting obstacles.* But the wheels may be made too large; for, if the radius exceeds the height of the horse's breast, the wheel will not only be unwieldy, but, the line of draught being inclined downward, a part of the power will be exerted in pressing the wheel against the ground.

On uneven roads, a slight inclination of the spokes, called *dishing*, tends to increase the strength of the wheel; because, when the wheel sinks into a cavity, the pressure is still exerted in the direction of the spokes.

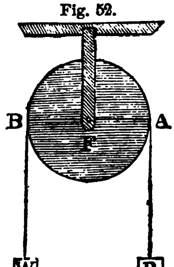
110. THE PULLEY.

A *pulley* is a small grooved wheel movable about an axis.

A *fixed pulley* is one whose axis is fixed.

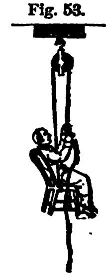
A *movable pulley* is one whose axis is movable.

Fig. 52.



A pulley may be regarded as *a lever with equal arms*, the arms being the radii of the wheel, AF, BF. Hence, in a fixed pulley, the power is equal to the weight, and no mechanical advantage is gained. It, however, often renders the power more available by permitting us to apply it in any desired direction, as in drawing a bucket from a well, raising the sails of a ship, or elevating stone for purposes of building.

Fig. 53.

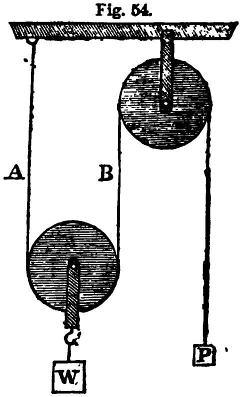


By means of a rope and a fixed pulley, a man may raise himself to a considerable height, or descend to a corresponding depth. If he be placed in a basket attached to one end of a rope which is carried over a

fixed pulley, by laying hold of the rope on the other side, and allowing the rope to slip slowly through his hands, he may at pleasure descend to a depth equal to half the length of the rope.

111. When a single movable pulley is used, and the cords on each side of the pulley are parallel, *the power is half the weight;* for the weight, W, is divided equally between the two strings, A and B; that is, each of these strings sustains half the weight; and, since the tension of the string is the same throughout, the power, P, sustains the same load as the string B.

Fig. 54.

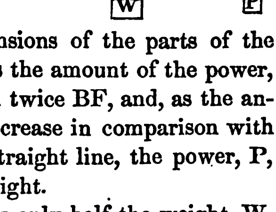


A fixed pulley is commonly associated with a movable one, the object of the former being to change the direction of the power.

Experiment.—With a single movable pulley, a power of 8 ounces balances a weight of 16 ounces.

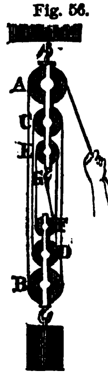
112. If the parts of the cord BC and BD be *not parallel, the power must be greater than half the weight.* Draw BA in a vertical direction to represent the weight, W; from A draw AF parallel to BC, and AE parallel to BD. The force AB may be regarded as the resultant of the two forces, BF and BE, which represent the tensions of the parts of the cord BD and BC, and each represents the amount of the power, P. It is evident that AB is less than twice BF, and, as the angle CBD increases, the power must increase in comparison with the weight. To draw CBD into a straight line, the power, P, must be infinitely greater than the weight.

Fig. 55.



Experiment.—When the power, P, is only half the weight, W, there is no equilibrium. When the power is equal to the weight, the triangle ABE becomes equilateral, and the angle CBD is 120°. The line CBD does not become straight, until the power becomes infinite in comparison with the weight.

Fig. 56.



113. In a system of pulleys, where the same string goes round all the pulleys, the weight is divided equally between all the strings at the lower block. If, therefore, the number of strings be 4, each string must support $\frac{1}{4}$th part of the weight. If the number of strings be n, each string must support $\frac{1}{n}$th part of the weight.

The number of strings at the lower block is double the number of movable pulleys.

Experiment 1.—In a system of two movable pulleys, a power of 5 ounces balances a weight of 20 ounces.

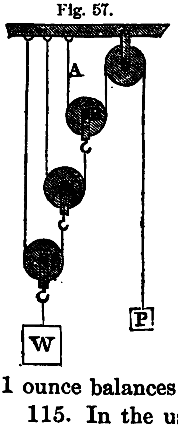
Experiment 2.—In a system of three movable pulleys, a power of 3 ounces balances a weight of 18 ounces.

In the system invented by Smeaton, the fixed and movable blocks each contain *ten pulleys*, commonly called *sheaves.* The number of parts of the cord supporting the lower block is 20, and, consequently, the power is to the weight as 1 to 20.

Experiment.—In Smeaton's pulley, a weight of 1 ounce balances a weight of 20 ounces.

Example.—What power will be necessary to sustain a weight of 5000 pounds in a system of 10 movable pulleys, where the same string goes round all the pulleys? *Ans.* 250 pounds.

Fig. 57.



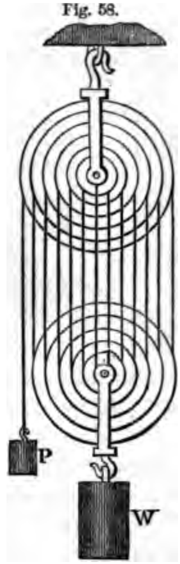
114. When *each pulley has a separate string,* since the first string, A, goes over a single movable pulley, the power, P, is half the weight sustained by the pulley B. For the same reason, the weight sustained by the first movable pulley, B, is half that sustained by the second, C, and this is half that sustained by the third, D, and so on; so that, with three movable pulleys, the power is one eighth part of the weight; and with four movable pulleys, the power is one sixteenth part of the weight.

Experiment.—In a system of 4 pulleys, where each pulley has a separate string, a weight of 1 ounce balances 16 ounces.

115. In the use of pulleys, there is *a great loss of power from friction.* In complex systems, two thirds of the power is ex-

pended on the machinery. Much of this friction arises from the play which is necessarily allowed to the pulleys, in consequence of which they are liable to rub against the sides of the frames in which they are inclosed. This evil is partly obviated in *White's Pulley*, which consists of several pulleys, all working on a common axis. It is, however, necessary that these pulleys should have *unequal diameters*; for, if several pulleys of the *same diameter* have a common axis, since they tend to revolve with unequal velocities, the rope must slip upon them, and thereby occasion a great amount of friction. But if their diameters were so adjusted that, in case they all had independent axes, they would revolve in the same time, the rope would pass over the grooves without sliding or scraping. This is effected in White's Pulley. If the wheels all have the same diameter, then, commencing at the fixed end of the string, while the first movable pulley makes *one* revolution, the first fixed pulley makes *two* revolutions, the second movable pulley *three*, the second fixed pulley *four*, the third movable pulley *five*, etc. Hence, if the diameters of these several wheels followed the ratio of the numbers 1, 2, 3, 4, 5, etc., they would all revolve in the same time; that is, in White's Pulley, the diameters of the movable wheels are as the numbers 1, 3, 5, etc., and the diameters of the fixed ones as the numbers 2, 4, 6, etc. This pulley entirely obviates lateral friction, and that shaking motion which is so inconvenient in the common pulley.

Fig. 58.



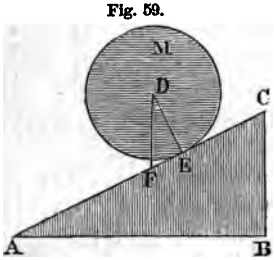
116. The pulley is the power almost exclusively employed in managing the rigging of ships, and it is extensively employed for *raising heavy weights to great heights*, as large masses of stone, etc. The columns of the New York Exchange are 38 feet high, and weigh 45 tons. It would be difficult to raise such columns to their places without the use of pulleys.

117. THE INCLINED PLANE.

The *inclined plane* becomes a mechanical power in consequence of its supporting a part of the weight.

The power which sustains a weight upon an inclined plane may act in any direction; but the most common case is that in which the *power acts parallel to the plane.*

Fig. 59.



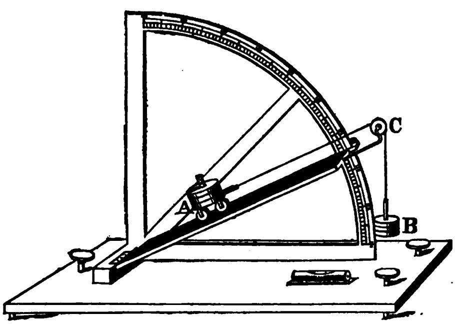
Let M be a body resting upon the inclined plane AC, whose height is BC, and let DF represent the weight of the body. Draw DE perpendicular to AC. The body, M, is acted upon by *three forces.*

1st. *Gravity*, which acts in a vertical direction, and is represented by DF.

2d. *The reaction of the plane*, which is exerted in a direction perpendicular to the plane, and is represented by DE.

3d. *The power* which sustains the body on the plane, and is represented by the line FE. Thus the three forces are represented by the sides of the triangle DEF, or the similar triangle ABC; that is, *the power* : *the weight* :: FE : DF :: BC : AC :: *the height of the plane* : *its length.*

Fig. 60.

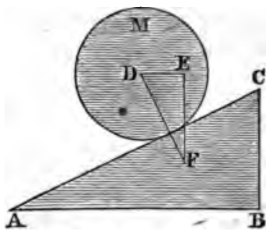


118. This law may be demonstrated experimentally. A plate of polished glass is used for the inclined plane, and the body employed consists of a carriage, A, resting on wheels, in order to diminish the friction. The carriage is counterpoised by a weight, B, attached to a cord passing over a pulley, C, at the top of the plane.

When the height of the plane is to its length as	1 : 10,	a power of 3 oz.	supports a load of	30 oz.
	1 : 5,	" 3 "	"	15 "
	1 : 2,	" 3 "	"	6 "

119. When the power acts *parallel to the base of the plane*, the force of gravity may be represented by the vertical line EF, the reaction of the plane by the line DF, drawn perpendicular to the plane AC, and the power which sustains the body on the plane may be represented by the line DE, parallel to the base. Hence, when there is an equilibrium, *the power* : *the weight* :: DE : FE :: BC : AB :: *the height of the plane* : *its base*.

Fig. 61.



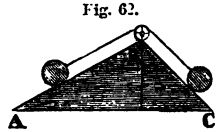
By means of an inclined plane, a very heavy load may be raised to any height, if we allow it sufficient time. It is supposed that the blocks of stone composing the pyramids of Egypt were elevated by means of the inclined plane. The inclined plane is still used for raising stone for large buildings; but this arrangement is now generally superseded by the steam-engine acting through the medium of pulleys.

120. *Roads* which are not perfectly level may be considered as *inclined planes*. The inclination of a road is commonly described as 1 foot in 25, or 1 foot in 30, meaning that, for a distance of 25 or 30 feet, the difference of level is 1 foot. Hence, if a road rises 1 foot in 20, a power of 1 ton will be sufficient to sustain upon the road a load of 20 tons.

Inclined planes are of daily use on *rail-roads*. If the road rises 1 foot in 100, a power of 1 ton will be sufficient to sustain a load of 100 tons.

Sometimes a weight upon one inclined plane, AB, is raised or supported by another weight upon a second inclined plane, BC. More frequently, both weights rest upon the same plane, AB, being connected by a rope which passes over a wheel placed at the top of the hill. This method of transportation was formerly employed in crossing the Alleghany Mountains in Pennsylvania. Loaded cars descended in one direction, while other cars which were connected with them by a rope, were drawn up in the opposite direction.

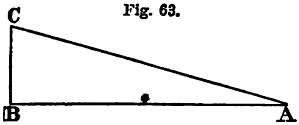
Fig. 62.



121. THE SCREW.

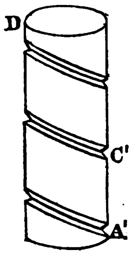
The principle of *the screw* is similar to that of the inclined plane.

Fig. 63.



If we take a piece of paper, ABC, cut in the shape of a right-angled triangle, whose base is much greater than its height, and wind it about a cylinder so that the base of the triangle may be perpendicular to the axis of the cylinder, the hypothenuse will trace a screw line upon its surface. This line is called the *worm* or *thread of the screw*, and each complete turn is called a *spire*.

Fig. 64.



The distance between two contiguous threads corresponds to *the height of an inclined plane*, and the circumference of the cylinder to *the base of the plane*. In revolving the screw, the power is exerted in a direction parallel to the base; hence, as in the inclined plane, there is an equilibrium between the power and the weight, when *the power* : *the weight* :: *the height of the plane* : *its base* :: *the distance between two contiguous threads of the screw* : *the circumference of the cylinder.*

122. When, as is usually the case, *a lever* is combined with the screw, the effect of the power is increased in the ratio of the radius of the cylinder to the length of the lever; or, the circumference of the cylinder to the circumference described by the end of the lever. Hence, when there is an equilibrium, *the power* : *the weight* :: *the distance between two contiguous threads of the screw* : *the circumference described by one revolution of the power.*

Example.—What weight can be sustained on a screw by a power of 2 pounds, having a leverage of 3 yards, the distance between the threads being one inch?

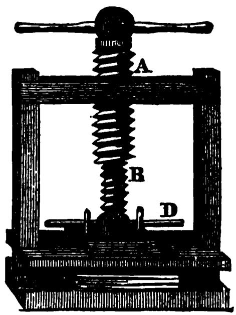
Ans. $P : W :: 1 : 2 \times 3 \times 3 \times 12\pi \therefore W = 432\pi = 1357$ pounds.

No account is here taken of *friction.* In practice, the friction alone generally exceeds the weight. If it were otherwise, the screw would not retain its place, and for most purposes would be useless.

123. *The power of the screw may be increased* by diminishing

the distance between the threads, or increasing the length of the lever; but there is *a limit* to the increase of power in either of these ways; for if the distance between the threads is too small, they become too weak; if the lever be too long, it becomes unwieldy. These evils are obviated by *Hunter's Screw*. This consists of two screws, A and B, having threads of *unequal* fineness, the smaller of which, B, works within the other. While the screw A *descends*, the other, B, *ascends* within it, and the weight D advances by the difference between the threads of the two screws. Hence, in this case, *the power* : *the weight* :: *the difference between the intervals of the two threads* : *the circumference described in one revolution of the power*. In this way, the efficacy of the power may be increased to almost any extent, without impairing the strength of the screw.

Fig. 65.

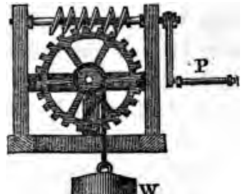


124. A screw may be cut upon a cylinder by placing the cylinder in a turning-lathe, and giving it a rotary motion upon its axis. The cutting point is then applied to the cylinder, and moved in the direction of its length, at such a rate as to be carried through the distance between the intended threads, while the cylinder makes one revolution.

The screw is chiefly employed where *great pressure* is required to be exerted *within a small space*, as in compressing cotton and other goods, for pressing books, for extracting juices from solid substances, etc. The screw is also extensively applied to the propelling of steam vessels, and it has several advantages over the common wheels.

125. When the threads of a screw act upon teeth inserted in the circumference of a wheel, it is called the *endless screw*. By the addition of a wheel, the effect of the screw is increased in the ratio of the radius of the axle to the radius of the wheel.

Fig. 66.



The endless screw is employed in

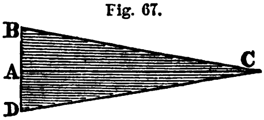
the engine for graduating the circles of astronomical instruments.

126. The screw is often employed for the measurement of very minute motions and spaces, and is then called *the micrometer screw.* Suppose a screw to be made with 100 threads to an inch; then each revolution of the screw will advance its point through the hundredth part of an inch. Suppose the head of the screw to be a circle whose diameter is one inch: its circumference will be more than three inches, and may easily be divided into 100 equal parts. The motion of the screw through one division of the head will accordingly advance the point through $\frac{1}{10000}$ of an inch. In order to observe the motion of the point of the screw, it is connected with a fine wire, which is placed in front of a powerful microscope, by which the motion is magnified so as to be perceptible.

127. THE WEDGE.

The principle of *the wedge* is analogous to that of *the inclined plane.* When the wedge is applied *by pressure,* it is simply an inclined plane with the power acting parallel to the base; for the conditions of equilibrium will be the same, whether the wedge be pushed under the load, or the load be drawn over the plane. Hence, when there is an equilibrium, *the power* : *the weight* :: *the thickness of the back of the wedge* : *the length of its side.* Wedges are generally formed of two inclined planes, BAC, DAC, joined base to base, the thickness of the wedge being the sum of the heights of the two inclined planes. Hence, *the power applied to the back of the wedge is to the resistance, as half the thickness of the back is to the length of the wedge.*

Fig. 67.



But when, as is generally the case, the wedge is driven forward *by percussion,* its power is not easily estimated. In general, the thinner the wedge, the greater is the efficacy of the power applied.

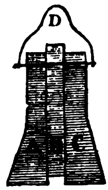
128. The wedge is generally used in the arts when *an intense force* is required to be exerted through *a small space.* It is sometimes used for raising heavy bodies, as ships in docks; but more frequently it is employed for dividing or splitting blocks

of stone or logs of wood. Its edge being inserted into a fissure, the wedge is forced in by blows upon its back. It is kept from recoiling by the friction of its sides. Its efficacy in this case depends entirely on friction.

All cutting instruments, as knives, chisels, axes, etc., are modifications of the wedge. *The angle of the wedge* depends upon the purpose to which it is applied. In tools for cutting wood, the angle is about 30°; for iron, from 50 °to 60°; and for brass, from 80° to 90°. In general, tools which are urged by pressure may be made sharper than those which are driven by a blow.

129. There is a contrivance in common use which is called a *Lewis*, and acts upon the principle of the wedge, which is employed for raising large blocks of stone in building. It consists of three parts, A, B, C, which are inserted successively into a hole of corresponding shape drilled in the stone, the middle part being inserted last. When the three parts are bolted together, they can not be withdrawn from the stone without breaking it; and the stone may be lifted by the ring, D.

Fig. 68.



130. There is one important principle applicable to each of the mechanical powers, viz.: *When two bodies counterpoise each other by means of any machine, and are then made to move together, the masses of the bodies are inversely as their velocities.* This may be shown,

1. With the lever:

When the power : the weight :: 1 : 4,

The velocity of the power : the velocity of the weight :: 4 : 1.

2. With the wheel and axle:

When the power : the weight :: 1 : 64,

The velocity of the power : the velocity of the weight :: 64 : 1.

3. With the pulley, in every form of application:

When the power : the weight :: 1 : 12,

The velocity of the power : the velocity of the weight :: 12 : 1.

4. With the inclined plane (both motions being estimated in a vertical direction):

When the power : the weight :: 1 : 10,

The velocity of the power : the velocity of the weight :: 10 : 1.

5. With the screw:

When the power : the weight :: 1 : 100,

The velocity of the power : the velocity of the weight :: 100 : 1.

131. *An indefinitely small power may therefore* (by means of machinery) *raise an indefinitely great weight, but the time required to accomplish it will be proportionally long.*

This principle will enable us to determine the ratio of the power to the weight in all cases, however complicated the machinery. It is even immaterial if the machinery be entirely concealed from our view.

It follows from this principle that *no momentum is gained by machinery.* If by machinery a small power is made to balance a great weight, the velocity of the weight when in motion is proportionally diminished; indeed, in consequence of friction, every machine transmits less force than it receives.

Archimedes boasted that if he could find a fulcrum, *he could move the earth with a lever.* We will admit what Archimedes claimed; but the velocities of the two bodies when in motion must have been inversely as their weights, and it has been computed that Archimedes must have traveled with the velocity of a cannon ball for a million of years, to have moved the earth $\frac{1}{27,000,000}$ of an inch.

132. *What, then, are the advantages gained by machinery?*

1. It often enables us to *exert our whole force in a useful manner.*

Thus, if a man were engaged in winding thread, it might not require the fiftieth part of his strength to turn a single reel. Machinery would enable him to turn fifty spools at once.

2. It enables us to *apply our power more advantageously by changing its direction.* Thus, in raising the sails of a ship, it is more convenient to stand on deck than to go to the top of the mast.

The wind which turns the arms of a windmill moves in a straight line, but by the intervention of machinery this force produces a rotary motion of the mill-stones.

The motion of the piston of a steam-engine is reciprocating, but by machinery it is made to impart a continuous motion in a straight line to a railway-train.

3. It enables us to *accomplish what we could not do without machinery.* Thus, by means of a lever, a man may lift a rock which he could not move with his naked hands. But no mo-

mentum is created by the lever, for the momentum of the man is just equal to that of the rock; and if the rock could be divided into small portions of convenient size, he might raise them all to a given height with his naked hands, in the same time that he is raising the united mass with the lever.

4. It enables us to *apply to useful purposes the powers of Nature, as wind, water, steam, and the strength of animals.* This is the most important use of machinery.

Machines, therefore, *do not create power:* they only *apply it;* indeed, the best machines *waste power*, because they will not operate without friction.

133. PERPETUAL MOTION.

Many ingenious mechanics have labored long to discover a *perpetual motion.* By perpetual motion in mechanics we understand not simply a motion that never ceases. The Falls of Niagara never cease; the rotation of the earth never ceases; the planetary motions never cease.

By perpetual motion in mechanics we understand a *machine which moves without ceasing, and requires no new application of force from without.* A machine which *renews itself* (as, for example, a watch which runs for 24 hours, and then *winds itself up*, so as to be ready to run another 24 hours, without any assistance from beyond itself) would be such a perpetual motion as has been long sought for by visionary inventors. A machine of this kind is *impossible*, because no combination of machinery produces any positive increase of power. Various contrivances have been devised in the hope of producing perpetual motion. The following is one of them. The annexed figure represents a large wheel, carrying twelve equal arms, each bearing at its extremity a heavy ball, and movable on a hinge, so that on one side of the wheel they rest near the circumference, while on the opposite side they stand out in the direction of radii.

Fig. 60.

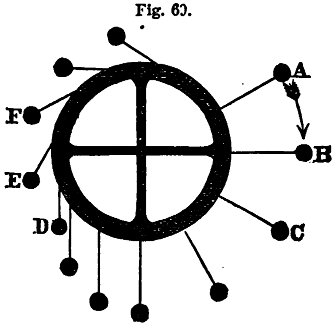
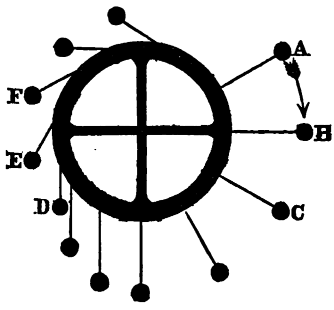


Fig. 70.



When the wheel is revolved in the direction ABC, the balls A, B, C stand out from the centre of the wheel, while on the opposite side the weights D, E, F lie close on the circumference. The former (being at the greatest distance from the centre) act with the greatest power, and tend to turn the wheel; and, since new arms are continually thrown out as the wheel revolves, the wheel, it is said, will continue to turn in the same direction. But experiment proves that this machine *will not go;* and the reason is, that although the balls on the right side are *farther from the centre* than those upon the left side, there is *a less number* of them on the right side. A great many machines have been proposed for producing perpetual motion, but they have all failed, and generally for a reason similar to the one here mentioned.

134. REGULATION OF FORCE.

Regularity is indispensable in the operation of most kinds of machinery. Sudden changes of motion are *always injurious*, and *sometimes destructive* to machinery.

Irregularity in the motion of machinery may arise,

1. From *variation in the power*. The power of steam varies with the intensity of the combustion; the force of wind is capricious; the force of animal power depends on the temper and health.

2. From *variation in the resistance*. In large establishments for spinning, printing, etc., a large number of separate looms, presses, etc., are usually driven by a common power, and a portion of them are liable to be occasionally and irregularly suspended.

3. *The power and resistance may both vary, but not proportionally to each other.*

135. Contrivances designed for securing uniform motion are called *regulators.*

The regulators in most common use are the following:

I. *The pendulum.* This regulates the descent of the weight of a clock, so that the hands are made to revolve with uniform velocity. The balance wheel of a watch regulates the action of the mainspring in a similar manner.

II. *The fly-wheel.* This is a heavy wheel, generally of iron, and is often attached to a steam-engine. The steam drives the piston backward and forward in the cylinder, and this power is required to give steady motion to a crank. The crank, during each revolution, comes successively into the positions marked 1, 2, 3, and 4. In the position No. 1 the rod CB has its *full power* to turn the crank AB round the centre A. In the position No. 2, the force in the direction BC has *no effect* in turning the crank

Fig. 71.

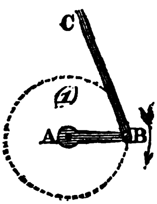


Fig. 72.

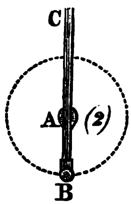


Fig. 73.

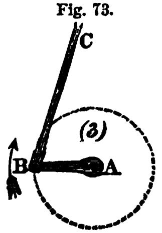
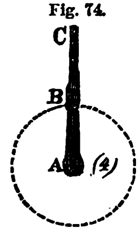


Fig. 74.



round A, but is entirely expended on the pivots which support the axle. In the position No. 3, the power acts with *the greatest efficacy;* but in the position No. 4, it again *loses all its efficacy* to turn the axle. Twice, therefore, in every revolution, the crank would come to rest, were it not for the effect of inertia. The momentum of the fly-wheel maintains a tolerably uniform motion of the crank, notwithstanding the variable action of the power.

136. A long horizontal lever, with equal arms, having a heavy ball attached to each end, was formerly employed in *coining and stamping metals.* This lever gives motion to a screw, at the lower end of which is the die for impressing one side of the coin. Medals are struck by successive blows of the die.

In all these cases the fly *creates no power:* it only *applies* that which is impressed upon it.

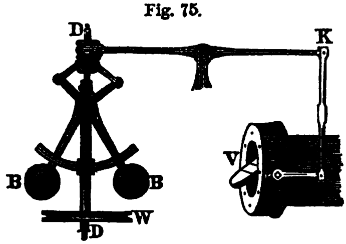
The fly-wheel is often employed for *the accumulation of force,* in cases where a severe instantaneous action is required. In

rolling-mills, the power of the water or steam is allowed to act for some time upon the fly-wheel alone. When sufficient momentum has been imparted to it, the metal to be rolled is placed under the machine, and receives the whole effect of the accumulated momentum.

The open work of fenders, fire-grates, etc., is punched in a similar manner, with the assistance of a fly-wheel.

137. III. Another regulator in common use is called *the Governor*. This contrivance consists of two heavy balls, B, B, attached to two arms suspended from a vertical axis, D, D, so that when the axis revolves rapidly, the arms are thrown outward by centrifugal force, and communicate motion to a lever, DK. In cotton and woolen factories a governor is always employed, whether the moving power be water or steam. If water is employed, the lever which is moved by the governor controls a gate which determines the supply of water to the wheel. If steam is employed, the lever DK turns a valve, V, which regulates the supply of steam. When the velocity of the machine becomes too great, the balls recede from the axis, the valve is partially closed, and the supply of steam is diminished. When the velocity becomes too small, the balls fall nearer the axis, the valve is opened, and the supply of steam is increased. Without some such contrivance, the machinery would move irregularly, either from changes in the moving power or changes in the load.

Fig. 75.



The effect of a variable power is sometimes rendered uniform by transmitting it through a leverage so regulated that as the power diminishes the leverage increases. We have an example of this kind in a common watch, where the power of the mainspring when it is first wound, is applied to the smallest part of the fusee; but as the spring uncoils, and its force diminishes, the radius of the fusee upon which it acts gradually increases.

SECTION VI.

FRICTION.

138. Friction arises from two sources:

I. *From inequalities of surface.*

When one rough surface is dragged over another, the eminences of one surface sink into the cavities of the other, and these eminences must be lifted out of the cavities, or they must be bent or broken off. This effect is observed when one rough board rubs upon another. The same cause operates to some extent whenever one body is moved upon another, for all bodies are rough, as appears when they are examined with a microscope.

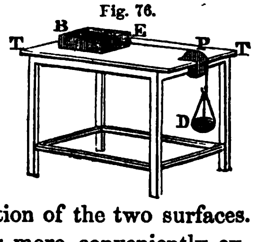
II. Friction arises from *cohesion of the parts*, so that friction would not be entirely annihilated, even if the surfaces could be made perfectly smooth. Thus, when two smooth glass plates are pressed firmly together, they adhere with great force.

139. We shall consider first *the friction of sliding bodies.*

The amount of friction of sliding bodies may be measured as follows:

A block of wood, BE, or any other substance having a smooth surface, is laid upon a smooth horizontal table, TT. A cord is attached to the block, and is carried over a pulley, P, fixed to one side of the table, so that various weights may be suspended from its extremity. The weight required to be attached to the string in order to move the block, is a measure of the friction of the two surfaces. The amount of friction is in most cases more conveniently exhibited by the spring steelyard, which requires no time for its adjustment.

Fig. 76.



140. The following principles have been discovered by experiment.

I. *Extent of surface makes very little difference in regard to friction.*

Thus a brick exerts nearly the same friction whether it rests upon its side or upon its edge. This law fails in extreme cases,

the friction being somewhat increased by a very great increase of surface.

II. *Friction is nearly proportional to the pressure.*

Thus, if the friction be 4 pounds when the weight is 10 pounds, the friction will be 8 pounds when the weight is 20 pounds.

III. *Friction is increased by bodies remaining some time in contact with each other.* Two pieces of wood acquire the utmost friction in two or three minutes; but iron, sliding on oak, has its friction augmenting for five or six days.

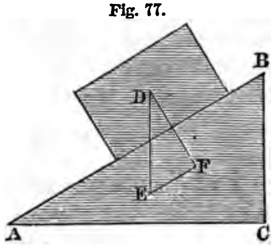
IV. *Friction is greatest at the first moving of a load.* Sometimes it is reduced one half when the body is put in motion. This is seen in experiments with the spring steelyard.

V. *Friction is less between surfaces of different kinds, than between those of the same kind.* Iron slides on brass more easily than iron on iron, or brass on brass. This principle is habitually applied in the joints of mathematical instruments, the two portions of the joint which rub against each other being made of different metals.

The friction of steel on ice is less than that of any other two substances, being less than two per cent. of the weight, while that of woolen cloth on woolen cloth is nearly 50 per cent.

141. *The angle of elevation* at which a body begins to slide upon an inclined plane is called the *angle of friction.* The amount of friction can be computed from the angle of friction. Let DE represent the weight of a body placed upon the inclined plane AB. Resolve this force into the two components DF, perpendicular to the plane, and EF, parallel to it. DF represents the pressure on the plane, while EF is the force which urges the body down the plane; and when the body begins to slide, EF represents the friction on the plane.

Fig. 77.



Hence the friction : the pressure on the plane :: EF : DF :: BC : AC :: tang. A : 1; that is,

the friction = the pressure × the tangent of the angle of friction.

When the angle of friction is 20 degrees, the friction is 36 per cent. of the pressure.

The following table shows the amount of friction between various substances.

	Angle of Friction.	Friction.
Woolen cloth and woolen cloth	23° 30′	0.430
Brass and brass	9° 57′	.176
Cast iron and cast iron	9° 17′	.163
Brass and cast iron	8° 00′	.140
Hard wood and hard wood	7° 43′	.135
Ice and ice	1° 35′	.028
Steel and ice	0° 49′	.014

142. *The friction of rolling bodies* is much less than that of sliding bodies. This arises from the fact that the inequalities of surface are not necessarily broken down before motion can ensue. Rolling friction may be increased by pressure. This is seen in the process of rolling metals between heavy cylinders. The friction of a heavy load is greatly reduced by placing it on rollers. The wheels of carriages may be regarded as rollers which are continually carried forward with the load.

On a well Macadamized road, when in good order, the resistance does not exceed three per cent. of the load. On a straight and level railway, the resistance is about one half of one per cent.

143. *Each of the mechanical powers involves friction.*

The friction of the lever is very small, generally 2 or 3 per cent.

That of the wheel and axle varies from 8 to 10 per cent.; but if the axle rests on friction wheels, the friction is much less.

The friction of the pulley varies from 20 to 60 per cent.

The friction of the inclined plane is small, when (as is generally the case) bodies are made to *roll* upon it.

The friction of the screw and wedge is very great, and must always exceed the resistance, or they would be of little value.

144. When a power is required merely to *support a weight*, the greater the friction, the less will be the power necessary to support the weight; but if a power is required to *move a weight*, the greater the friction, the greater will be the power required.

When a machine is employed simply to sustain a weight, the friction becomes a mechanical advantage, and in many cases the entire efficiency of the instrument is due to this resisting force. This is true of screws and nails, which would not hold without

friction, and the same is the case with the wedge as it is ordinarily employed.

Without friction most structures would fall to the ground. Without friction we could not hold any object in our hand; a locomotive engine could not draw its load, and animals could not walk or exert their strength.

SECTION VII.

STRENGTH OF MATERIALS.

145. *A solid body may be subjected to strain* in various ways, of which the following are the principal:

1. *A direct pull*, as when a weight is suspended from a hook by a wire.

2. *A direct thrust*, as when a weight rests upon a column.

3. *A transverse strain*, as when a weight is suspended from a horizontal beam, supported at both ends.

4. When a force is applied to *twist a body asunder.*

The strength of a rod, rope, or wire to resist a direct pull is proportional to *the area of a cross section.* The amount of this strength is determined by securing one extremity of the rod to a point of support, and suspending weights from the other extremity until the rod breaks. The following table shows the number of pounds supported by prisms of various substances, each having a section of one square inch.

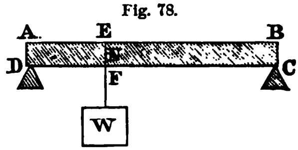
Tempered steel...	134,000	pounds.	Box wood...........	19,000	pounds.
Malleable iron....	64,000	"	Ash wood...........	18,000	"
Brass wire.........	53,000	"	Oak wood...........	18,000	"
Hammered copper	38,000	"	Elm wood...........	12,000	"
Cast iron...........	18,000	"	Pine wood..........	12,000	"
Lead wire..........	3,000	"	Twisted Hemp......	6,000	"

The following table shows the weights necessary to *crush* pillars of various substances, each having a section of one square inch.

Brass................	164,000	pounds.	Marble and granite	10,000	pounds.
Cast iron...........	146,000	"	Sandstone...........	2,500	"
Wrought iron.....	72,000	"	Brick..................	1,000	"
Lead.................	7,000	"	Oak wood...........	6,000	"

146. In order to estimate *the strength of a beam to resist a transverse strain*, let ABCD be a rectangular beam, supported horizontally at its extremities C and D, and sustaining a weight, W, placed at some intermediate point, E. The tendency of the weight is to rupture the fibres of the beam; and if the fibres were wholly *incompressible*, the fracture would commence at the lowest point, F, and pass successively through all the laminæ until it arrived at the point E, thus causing the beam to turn round the point E as if it were a hinge.

Fig. 78.



If, on the contrary, the fibres were wholly *inextensible*, then, if the beam turned at all, it must be about the point F, and every fibre from F to E would be in a state of compression. But all bodies are capable both of extension and compression, and, therefore, the beam will turn, not about E or F, but about an intermediate point or line, N, and all the fibres below that line will be in a state of tension, and those above it in a state of compression, while those at N will be neither extended nor compressed. The line N is called *the neutral axis of rotation*, and, from numerous experiments on rectangular beams, EN is found to be to NF as 5 to 3.

The ability of the beam to resist fracture will depend partly upon *the number of the fibres*, and partly upon *the distance of each fibre from the neutral axis;* for the neutral axis may be regarded as the centre of motion of a rectangular lever, to one arm of which the force of the fibres is applied. The fibres on the lower side of the beam act upon a lever whose length is NF, and each of the other fibres has a leverage proportional to its distance from the neutral axis. The average leverage by which the strength of the fibres resists rupture, is half the distance of the neutral axis from the under surface of the beam. The fibres above the neutral axis, which are in a state of compression, act with a similar leverage. Hence *the entire strength of the beam to resist fracture is proportional to the number of the fibres, that is, to the area of a cross section at E, multiplied by EF, the depth of the beam.*

147. The strength of a beam of a given section will therefore

be increased by any change of form or position which shall increase its depth.

Thus the strength of a rectangular beam, when *its narrow side* is upward, is to its strength when *its broad side* is upward, as its depth is to its breadth. The timbers for floors and roofs of buildings should therefore always be placed with their broad sides vertical.

If a solid and a hollow cylinder of equal lengths contain the same quantity of matter, their strength will be nearly proportional to the diameters of the cylinders. Hence the strength of a tube is greater than that of a solid rod containing the same quantity of matter.

We see applications of this principle in the hollow bones of animals; also in the stalks of grain, the quills of birds, etc.

SECTION VIII.

THEORY OF ARCHES AND DOMES.

148. *Theory of the arch.* An arch is composed of a number of solid bodies so arranged upon a curve as mutually to sustain each other. They generally have the lower side concave toward the horizon, and are supported at the extremities upon walls.

Arches may be classified according to the material of which they are built, as *stone or brick, wood, cast iron,* etc.

Fig. 79.

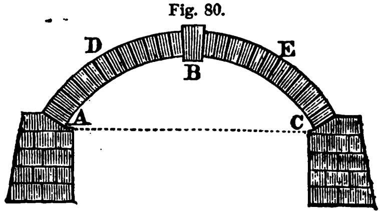
Arches of stone are composed of a number of prisms, whose section is a trapezoid, as shown in Fig. 79; these may be considered as *truncated wedges,* and are called *voussoirs.* They are generally of an uneven number; the odd one, which occupies the vertex of the arch, is called *the keystone.* The vertical walls on which they rest are called *abutments,* and when there are two contiguous arches, the intermediate wall is called *a pier.* The point where the vertical wall meets the curve of the arch is called *the spring* of the arch. The distance between the piers or abutments that support a single arch is called *its span.*

149. Arches are built by laying their voussoirs upon a temporary frame of wood, called *a centre,* whose upper surface has

the form it is intended to give to the arch. The lower voussoirs retain their position in consequence of the friction upon their faces, and may be laid independently of the centre. They do not begin to slide until the inclination of the faces becomes equal to about 40°. When the key-stone is placed, and the centre is removed, the arch, if sustained, is supported by the mutual pressure of the parts.

The weight of the upper part of the arch tends to crowd the lower parts *outward*. If the pressure is too great to be sustained, the arch *divides into four parts*, which, in breaking, turn around the points A, D, B, E, C, as upon hinges; that is, it divides at the vertex, at the abutments, and at two intermediate points. If the arch does not fall, the pressure is still shown by fissures in the lower surface, at A, B, and C, and in the outer surface at D and E. The position of the points D and E, which are called *points of rupture*, depends upon the figure of the arch and the distribution of the weight. In semicircular arches, the points of rupture are at an angle of 30° from the spring.

Fig. 80.



The best arches settle somewhat when the centre is removed. The arches of the bridge of Neuilly, near Paris, being 127 feet span, settled 23 inches, yet this is a perfectly safe as well as elegant bridge.

150. *The best figure for an arch* is determined by the following principles. If a chain, ABC, be suspended from its two extremities, the figure which it assumes when it hangs freely is called *a catenary*. If a large number of equal and solid spheres be strung upon a string and suspended in the same manner, they will come

Fig. 81.

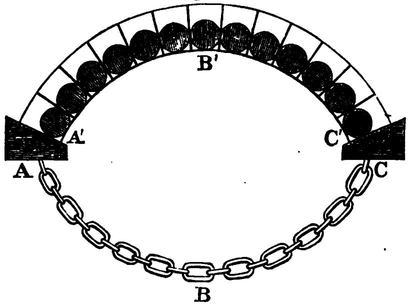
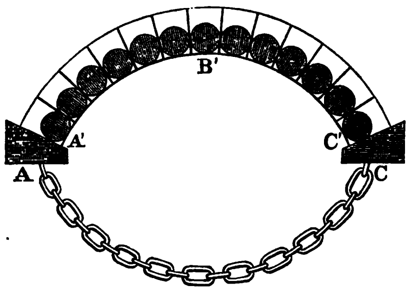


Fig. 82.

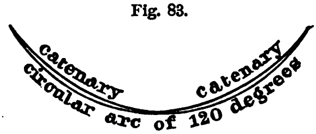


to rest upon the same curve. If, now, this curve be inverted without any change of form, and the extremities be made to rest upon abutments, D and E, the spheres will be supported, because the forces which act upon the spheres in the inverted position, may be represented by the same lines as in the direct position, with only this difference, that gravity, instead of tending to pull the string apart, tends to crowd the spheres together; that is, we have substituted a *compressing* in place of a *stretching* force. If the spheres are capable of resisting this compression, the arch will keep its figure unchanged as well in the inverted as in the erect position.

If the weights of the spheres are unequal, the curve of the catenary will vary accordingly; and if this arch be inverted (its figure remaining unchanged), it will still be sustained. Hence we conclude that *the form of the arch should be the same as that of the catenary, formed by a chain whose thickness at every point is proportional to the thickness of the arch.* The equilibrium of a system of spheres arranged upon a catenary would be *unstable*, and the slightest lateral pressure would overturn it. If the intervals between the globes be filled up, so as to convert the spheres into wedges, the equilibrium will be rendered *stable.*

151. *The centre of gravity should be made low,* in order that the arch may not be overturned. In this case the catenary differs but little from *a circular arc of* 120°; and since a circle is the most convenient curve to be described, the form of arches is generally that of a portion of the circumference of a circle. Sometimes the arch is made in the figure of a *semi-ellipse.* Arches of other forms are sometimes employed, but their strength is due to the fact that in their thick-

Fig. 83.



ness the catenary is included; and the strength of the arch is diminished in precisely the same degree that the figure departs from the catenary.

When a chain is loaded in the middle, the catenary becomes *pointed.* Hence *the acute arch* is adapted to sustain a load upon its vertex. It is much used in Gothic architecture.

Arches exert *a lateral pressure*, or *thrust*, tending to overthrow the abutments. The amount of this thrust may be estimated by considering the parts of the arch which rest immediately on the abutments, and which would retain their places though the arch was incomplete, as constituting a portion of the abutments themselves; and we must consider the remainder of the arch as *a wedge*, tending by its weight to *separate the abutments* from each other. This horizontal pressure must be resisted by loading the abutments.

152. The greatest stone arch of ancient or modern times is that over the Dee, near Liverpool, England, and which has a span of 200 feet.

The Romans were the first people who employed arches as a prominent feature of architecture. The oldest considerable arch in existence is that of the *Cloaca Maxima* at Rome, built by Tarquin 500 years before Christ, and some of the largest arches ever erected were built by the Romans.

The new bridge over the Thames, at London, consists of five stone arches, which are semi-ellipses, the central one having a span of 152 feet, the two next 140 feet each, and the two remaining ones 130 feet span. The entire length within the abutments is 782 feet, and its width is 53 feet.

The most remarkable stone arches in this country are those of the High Bridge near New York. It consists of 8 arches, each having a span of 80 feet, with 7 other arches, each having a span of 50 feet. The entire length of the bridge is 1450 feet, and its width on the top is 21 feet. The top of the bridge is 114 feet above high-water mark.

The Starrucca Viaduct, on the Erie Rail-road, is 1200 feet long, 110 feet high, and has 18 arches, with spans of 50 feet each.

153. *Wooden arches* may be constructed upon several different principles.

I. *A continuous arch* may be formed by uniting a large num-

ber of planks or wooden beams of moderate length, hewn or bent in such a manner as to have a uniform curvature, and secured together by bolts and iron straps, so that the joint connecting any two beams may be opposite to the middle of another beam with which they are connected. An arch thus constructed will not only sustain itself, but will support a heavy load, provided it be so braced as to prevent its changing its figure.

A bridge at Bamberg, in Bavaria, constructed upon this principle, has a span of 221 feet. In this bridge the road-way passes over the summit of the arch. The arch is therefore necessarily flat, and exerts a great lateral thrust.

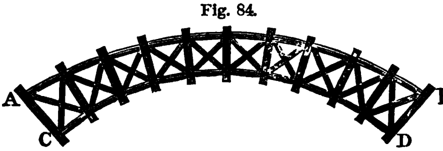
The bridge over the Delaware, at Trenton, is similar in principle, but the road-way is horizontal, resting on timbers supported by iron rods, which are attached to the arch, and hang vertically with their lower extremities nearly in the same horizontal line. These horizontal timbers form a continuous chord, uniting the extremities of the arch so as to counteract its horizontal thrust. This bridge has four arches of 194 feet span, and one of 156 feet.

Trajan's Bridge, over the Danube, was 2758 feet long, having 23 stone piers and abutments surmounted by wooden arches each about 120 feet span, and composing an arc of a circle but little exceeding 60 degrees in length.

The Cascade Bridge on the Erie Rail-road is constructed on the same principle. It is 276 feet in length, and 184 feet in height.

154. II. Straight beams may be arranged *in two parallel lines*, AB, CD, one above the other, forming *a double arch*, and interposing at equal intervals a series of transverse beams;

Fig. 84.



thus forming a collection of *quadrilateral frames* or *open voussoirs*. To prevent them from changing their figure, the opposite angles of each frame are united by additional beams in the form of a cross. At Portsmouth, N. H, is a bridge constructed upon this principle, having a span of 256 feet.

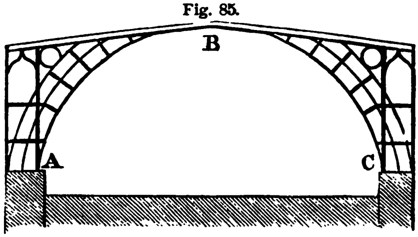
These two methods may be combined, as in the bridge erected

over the Schuylkill, near Philadelphia, which had a span of 340 feet, the largest wooden arch ever erected in America. This bridge was burned in 1845, and a wire bridge has been erected in its place.

155. *Cast iron arches* may be made of continuous bands of cast iron, in which case their theory is similar to the first-mentioned variety of wooden arches; or the material may be cast in skeleton voussoirs, in which case their theory is similar to that of stone arches. The latter form is preferable, because cast iron has no great tenacity.

The first cast iron bridge ever erected was that of Coalbrookdale, in England. It was erected in the year 1777, and has a span of 100 feet. The main support of this bridge consists of two portions, AB, BC, in the form of quadrants, meeting at the vertex of the arch, and together constituting a semicircumference. This bridge was constructed upon the principle first mentioned, and is not to be recommended for imitation.

Fig. 85.



Southwark Bridge, at London, consists of three arches, the central one having a span of 240 feet, and a height of 24 feet. The other two arches have a span of 210 feet each. These are the largest cast iron arches ever erected. This bridge was completed in 1819, and was constructed with such accuracy that when the centre of the middle arch was removed, it settled less than two inches. The main support of this bridge consists of hollow voussoirs, arranged as in a stone arch.

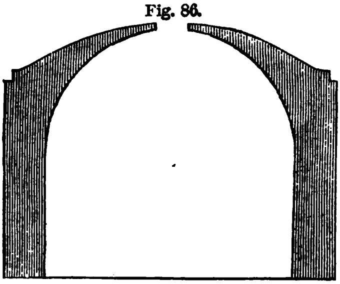
156. THEORY OF DOMES.

A dome is a curved roof, and is generally a portion of the surface of a sphere or spheroid. The chief difficulty in the construction of domes arises from the great height to which the base is often elevated above the ground, amounting in one instance to 250 feet. To sustain the weight of a large dome at such a height requires the greatest solidity in the supporting walls.

A dome is usually erected upon a cylindrical wall having the same diameter as is intended to be given to the dome, and this wall is carried to a height which overtops the main roof of the building. This cylinder is necessarily perforated for passage-ways, and sometimes the lower portion consists merely of four solid piers, which, at a considerable height, are connected by arches, forming a complete cylinder, upon which the dome is raised. The dome is built in horizontal courses of stone of one foot or more in thickness. By causing each stone to project inward a little beyond its base, the diameter of each course is made a little smaller than the preceding, and the inward pressure at any point of one course is balanced by an equal pressure on the opposite side. Thus each course of stone, even to the top, may be regarded as a complete arch with its key-stone. *An aperture of any dimensions*, either great or small, may therefore be left in the top of the dome, and the whole may be erected without any centering. The weight of the top of the dome tends to *crowd the base outward.* This tendency must be resisted by making the supporting walls thick and massive. When the walls are of great height, it is common to surround the base of the dome with a heavy chain or hoop of iron, to prevent the walls from being pushed outward.

157. The most remarkable antique dome now existing is that of the Pantheon, at Rome. This building has a circular ground-plan, on which is raised a cylindric wall 71 feet high, bearing a dome in the form of a hemisphere 142 feet in diameter. At the top is an opening 26 feet in diameter. The lateral thrust is counteracted by the weight of the walls, which are 21 feet in thickness.

Fig. 86.



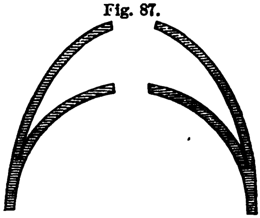
The dome of St. Sophia's, at Constantinople, erected under Justinian, A.D. 531–8, is remarkable for its small elevation. Its diameter is 115 feet, and its height 38 feet, or one third of the diameter; and the base of the dome is 145 feet above the floor. The lateral thrust is so great, owing to the flatness of the

dome, that, twenty years after its completion, the eastern half of the dome fell in. Again, in the year 987, a part of the dome fell a second time. The third time it was built of pumice stone, and its thickness diminished.

The next dome which deserves mention is that of St. Mary's, at Florence, erected between the years 1420 and 1440. The interior diameter of the dome is 133 feet, its height is 113 feet, and the base of the dome is 170 feet above the pavement. This dome is, in fact, a double dome, consisting of two parallel walls with an open space between them.

The most magnificent dome ever erected is that of St. Peter's church at Rome, built between the years 1506 and 1641. The exterior of the dome forms nearly a semi-ellipsoid, and at the height of 50 feet from its base, it branches into two thin vaults, which gradually separate from each other. The dome is 140 feet in diameter, and its base is 250 feet above the floor. The horizontal thrust is counteracted by strong hoops of wrought iron, bound round the lower courses of the dome.

Fig. 87.



The dome of St. Paul's, in London, has considerable beauty. It is 104 feet in diameter, and its base is 160 feet above the pavement. The inner dome is of brick, while the outer is a wooden frame covered with sheet lead. To support the frame which bears the outer dome, a truncated cone of brick rises from the inner dome, and is surmounted by a small cupola. The horizontal thrust is counteracted by a chain laid in a groove cut in the stone ring from which the dome springs.

The largest dome in this country is that of the Crystal Palace, in New York, which is 100 feet in diameter.

The dome of the Capitol at Washington is 96 feet in diameter.

SECTION IX.

TERRESTRIAL GRAVITY.

158. A small weight suspended freely by a thread from a fixed point forms *a plumb-line*.

The direction which the plumb-line assumes when it comes to a state of rest, is called *the vertical direction*.

The surface of an expanse of tranquil water is called *a level surface*, and this surface is perpendicular to the plumb-line.

The earth exerts an attraction upon all bodies placed near it. The direction of this attraction is indicated by the plumb-line, and is perpendicular to the surface of tranquil water.

If a body suspended above the earth's surface be disengaged, the earth's attraction will cause it to fall in the direction of a plumb-line—that is, in a vertical direction.

Gravity acts *equally* and *independently* on all the particles composing a body. Hence different masses of matter, however they may vary in magnitude and weight, will descend to the surface of the earth with the same velocity, provided they are affected by no other force than that of gravity.

If a feather and a leaden ball be let fall from the same height, they do not, indeed, descend with the same velocity; but this result is due to the resistance of the air, which is much greater upon the feather than upon the ball; for in a receiver, from which the air has been exhausted, we find that all objects fall together with a common velocity.

159. Since the attraction of the earth acts equally on all the parts of bodies, and since the *weight* of a body is but the result of this attraction, *the weights of bodies must be proportional to their quantity of matter*.

When a body falls freely under the influence of gravity, its velocity is accelerated as it descends; for while the body, in consequence of its inertia, retains the velocity acquired during the first second, gravity imparts to it an equal quantity of velocity during the next second, so that at the end of two seconds the velocity of the body is double what it was at the end of the first second. For the same reason, the velocity at the end of three

seconds is three times what it was at the end of one second; that is, *the velocity acquired by a body in descending by the force of gravity is proportional to the time of fall.*

When a body receives equal increments of velocity in equal times, it is said *to be uniformly accelerated.*

Gravity, therefore, acting on bodies near the surface of the earth, is a uniformly accelerating force.

160. Since a falling body moves with a uniformly accelerated velocity, its mean or *average velocity* will be that which it had precisely at the middle of the interval during which it falls. Hence *the final velocity*, acquired at the end of any time, will be *double the average velocity*, counted from the commencement of the fall.

Hence, *if a body were to move with its final velocity continued uniformly, it would, in a time equal to that of the fall, move over a space double of that through which it had fallen.*

Let g represent the height through which a body falls from rest in one second; the body in one second has acquired a velocity which (without the further action of gravity) would carry it over a space $2\,g$ in the next second; but, during the next second, gravity causes it to move over another space equal to g; that is, during the second second, the body moves through a space equal to $3\,g$, and during the first two seconds it moves through a space expressed by $4\,g$.

The body having now fallen through a height $4\,g$, has acquired a velocity which, without any further action of gravity, would carry it over a space equal to $8\,g$ in two seconds, or $4\,g$ in one second; but gravity, also, in the third second, would move it through a space g; hence, during the third second, the body will descend through a space equal to $5\,g$; and therefore, during the first three seconds, it will descend through a space $9\,g$. By a similar course of reasoning, we find that, during the fourth second, the body falls through a space $7\,g$; and therefore, at the end of the fourth second, it will have fallen through a space $16\,g$; and so on.

161. The following table presents these results in a condensed form. Column first shows the number of seconds in the fall, counted from a state of rest; column second exhibits the space fallen through in each successive second; column third shows

the velocities acquired at the end of the number of seconds given in the first column; and column fourth shows the total heights through which the body falls from a state of rest.

Number of seconds in the fall.	Spaces fallen each second.	Velocities acquired.	Total height fallen through.
1	g	$2g$	g
2	$3g$	$4g$	$4g$
3	$5g$	$6g$	$9g$
4	$7g$	$8g$	$16g$
5	$9g$	$10g$	$25g$
6	$11g$	$12g$	$36g$
7	$13g$	$14g$	$49g$
8	$15g$	$16g$	$64g$
9	$17g$	$18g$	$81g$
10	$19g$	$20g$	$100g$

From this table we perceive,

I. That *the spaces fallen through in each successive second vary as the series of odd numbers*, 1, 3, 5, etc.

II. That *the velocity acquired by a falling body is proportional to the time of fall.*

III. That *the space through which a body falls in any time is proportional to the square of the number of seconds.*

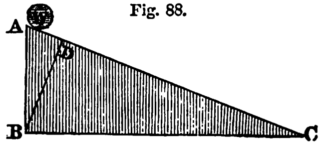
162. It is difficult to determine the laws of falling bodies *experimentally* on account of the velocity of their descent.

Through the height of an ordinary room a body falls in less than one second. A body falls from a height of 100 feet in less than three seconds. A ball of lead, weighing two pounds, dropped from the dome of St. Paul's Cathedral, in London, was only $4\frac{1}{4}$ seconds in falling 272 feet. When the velocities are so great, it is difficult to observe with sufficient precision the points at which the falling body arrives at each successive second.

It is important to discover some *method of reducing the velocity, without changing the law of acceleration.*

Two methods have been used for this purpose. The first method employs *the inclined plane*, and was tried by Galileo.

Fig. 88.



Let W be a body placed upon the inclined plane AC, the force of gravity acting upon it in the vertical direction, AB. Draw BD perpendicular to AC; then

AB (which we will take to represent the entire force of gravity) may be resolved into the two forces AD, BD; but BD, being perpendicular to the plane, produces merely pressure upon the plane, while AD represents the force which accelerates the body down the plane. This force has to the entire force of gravity the ratio of AD to AB, or AB to AC; that is, *as the height of the plane to the length.*

But the height of a plane has to its length *a constant ratio*, whatever be the length of the plane. Hence, upon an inclined plane, the accelerating force is constant; the body will therefore be *accelerated by the same law as if it fell freely*, but the velocity may be reduced at pleasure by diminishing the elevation of the plane.

Upon a plane 16 feet in length, whose height is one foot, a ball in one second will descend one foot; in 2 seconds, 4 feet; in 3 seconds, 9 feet; and in 4 seconds, about 16 feet.

In these experiments, the spaces are nearly proportional to the squares of the times; but the results are not very satisfactory on account of the friction upon the plane, and the friction increases as the elevation of the plane is diminished.

163. A better mode of experimenting is by means of *Atwood's Machine*, described on page 26. In this machine two nearly equal weights are connected by a fine thread, which passes over a grooved wheel turning on a horizontal axis. By making the *difference* of the weights very small, we may make the velocity of descent as slow as we please.

If we make the difference of the weights one ounce, while the sum of the weights is 100 ounces, the earth's attraction on the 99 ounces may be regarded as neutralized; but the one ounce in its descent is compelled to put in motion 100 ounces, so that the velocity of its descent will be only the hundredth part of that of a body falling freely; yet the law of acceleration is the same. The time of falling down the height of the machine is thus increased to 5 or 6 seconds.

There are four sources of error in these experiments.

1. *Friction.* By means of friction wheels the friction is greatly reduced, but can not be entirely annihilated.

2. *Resistance of the air.* With such small velocities as are commonly employed in these experiments, this resistance is scarcely perceptible.

3. *The weight of the string.* As one weight descends, a portion of the string is transferred from the side of the ascending weight to that of the descending weight, thus changing the ratio of the two weights. The effect of this transfer is diminished by employing a very fine thread to support the weights.

4. *Want of perfect accuracy in the weights employed.*

Notwithstanding these sources of error, very good results are obtained with this machine.

164. We will first make the accelerating force $\frac{1}{96}$ part of gravity. This is accomplished by making one of the weights $47\frac{1}{2}$, the other $48\frac{1}{2}$.

In 1	second	the weight falls	2	inches.
" 2	seconds	"	8	"
" 3	"	"	18	"
" 4	"	"	32	"
" 5	"	"	50	"

From these experiments we derive

LAW I. *The spaces described vary as the squares of the times.*

From these numbers we can also compute the space which would be described by a body falling freely.

When the accelerating force is $\frac{1}{96}$ part of gravity, the space described in one second is 2 inches. Hence, a body falling freely would describe 2×96, or 192 inches, which is 16 feet, per second, a quantity which we have heretofore represented by g.

If we make one of the weights $47\frac{3}{4}$, and the other $48\frac{1}{4}$, the accelerating force will be half as great as before, and the spaces described will be half as great.

In 5	seconds	the fall is	25	inches.
" 6	"	"	36	"
" 7	"	"	49	"
" 8	"	"	64	"

Hence the spaces described in 1, 2, 3, 4, etc. seconds, are proportional to the numbers 1, 4, 9, 16, etc.

The successive differences between these squares are 1, 3, 5, 7, etc.

Hence *the spaces described in equal successive portions of time, are as the numbers* 1, 3, 5, 7, 9, etc.

165. We will next determine how *the space described depends upon the accelerating force.*

When the accelerating force is	$\frac{1}{2}$ an ounce,	the space described in 2 seconds is	4 inches.
	1 "		8 "
	2 "		16 "
	3 "		24 "

From which we infer

LAW II. *The space described in a given time is proportional to the accelerating force.*

166. We will next determine the space described after the accelerating force is taken off. If the accelerating force be $\frac{1}{96}$, the fall in 2 seconds is 8 inches. If the excess of the descending weight be now taken off by a ring, the fall in the next 2 seconds will be 16 inches.

In 3 seconds the fall from rest is 18 inches.

In the next 3 seconds, the excess being taken off, the fall is 36 inches.

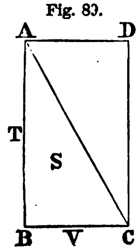
From which we infer

LAW III. *The velocity acquired by a body falling for any time is such as, if continued uniformly, would carry it over twice the space in the same time.*

We have found that the space described in one second by a body falling freely is 16 feet. Hence the velocity acquired in one second is 32 feet, which we have before represented by 2 g.

167. We have seen that in uniform motion the space described may be represented by *a right-angled parallelogram*, one side of which represents the time, and the other the velocity.

Fig. 83.



If AB represent the time of a body's fall, and BC the velocity acquired, then, with this velocity continued uniformly, the space described would be represented by ABCD; but, according to the last law, the space actually described is *one half* of this, and may therefore be represented by the triangle ABC; that is, *the space described by a body falling from rest under the influence of gravity, may be represented by a right-angled triangle, one side of which represents the time, and the other the velocity acquired.*

168. *The motion of an ascending body is retarded by the same law as that of a descending body is accelerated.*

To prove this, we make one of the weights $47\frac{1}{2}$ ounces, the other $46\frac{1}{2}$, and add to the latter a long bar weighing 2 ounces.

In 3 seconds the body falls 18 inches. We here place the ring to intercept the bar, and find that in the fourth second the descent is 10 inches; in the fifth second, 6 inches; and in the sixth second, 2 inches.

Hence *the spaces described by an ascending body in successive seconds, are as the numbers* 1, 3, 5, 7, 9, etc., *taken in the inverted order.*

If the long bar be retained for 4 seconds, the space described will be 32 inches. If we place the ring at this point, the space described in the fifth second will be 14 inches; in the sixth second, 10 inches; in the seventh second, 6 inches; and in the eighth second, 2 inches.

Hence *an ascending body loses its velocity in the same time in which it would be acquired by falling from rest.*

169. The preceding results are most concisely expressed by mathematical formulas. If T represents the number of seconds during which a body has been falling from rest, g the space fallen through in one second, and S the entire space fallen through; then

$$S = T^2 \times g.$$

Thus, in 10 seconds the space described is 1600 feet.

Since we have found that the velocity acquired in falling one second is $2\,g$, and the velocity is proportional to the time of fall, if we put V for the velocity acquired in the time T, we shall have

$$V = 2T \times g.$$

By comparing these two formulas, we have

$$V^2 = 4S \times g,$$

or

$$V = 2\sqrt{S \times g},$$

which enables us to compute the velocity acquired in falling through any height.

These principles are strictly true only for bodies falling in a vacuum.

In the case of bodies of small density, these results are very much modified by the resistance of the air.

Example 1. A body has been falling 9 seconds: what space has it fallen through, and what velocity has it acquired?

Ans. $S = 1296$, $V = 288$.

Example 2. How far must a body fall to acquire a velocity of 150 feet per second? *Ans.* 351 feet.

Example 3. Find the space described by a falling body in the ninth second of its fall. *Ans.* 272 feet.

Example 4. Calculate the time required for a falling body to descend 316 feet. *Ans.* 4.43 seconds.

Example 5. If a body falls through 216.17 feet, find the velocity acquired. *Ans.* 117.79 feet.

170. The force of gravity is not exactly the same at all points of the earth's surface. At the pole, the space fallen through in one second is 16 feet and 1½ inches, while at the equator it is 16 feet and a half inch; that is, the space described by a falling body in one second at the pole is one inch greater than at the equator. This result is due partly to the fact that the earth is not a perfect sphere, but a body at the pole is nearer to the earth's centre than a body at the equator; and partly to the centrifugal force arising from the earth's rotation upon its axis, by which a portion of the earth's attraction at the equator is neutralized.

171. According to the Newtonian law of gravitation, *every particle of matter attracts every other particle.*

This attraction is exhibited between comparatively small masses of matter. Thus the plumb-line is deviated from its vertical position by the attraction of a mountain. By the attraction of Chimborazo, a mountain in South America, the plumb-line was found to be deviated 8 seconds of a degree.

A distinguished English philosopher, by the name of Cavendish, undertook to measure the attraction exerted upon a small ball of lead, by a leaden ball 12 inches in diameter. His arrangement was as follows: A wooden rod 6 feet long was suspended in a horizontal position by a slender wire 40 inches long, and to each extremity of the rod was attached a leaden ball 2 inches in diameter. A sphere of lead 12 inches in diameter was placed near one of the balls, and a second sphere of the same size near the other ball, in such a position that both spheres tended to draw the rod in the same direction. The spheres were afterward moved to the opposite side of the balls, so as to draw the rod in the contrary direction. The attraction of the lead balls was found to be appreciable. See Philosophical Transactions, 1798, p. 469.

172. The diurnal rotation of the earth is proved by the phe-

nomena of falling bodies. Suppose we have a tower 300 feet high. On account of the rotation of the earth upon its axis, every point on the earth describes a circle about the axis, and the top of the tower will move in a larger circle than the base, since it is more distant from the earth's axis; that is, it will have a greater velocity from west to east than the base. If a ball be dropped from the top of the tower, it will have the same motion from west to east as the top of the tower; that is, during its fall it will be carried eastward through the space through which the top of the tower is carried, while the base of the tower is carried eastward through a less space. The ball must therefore fall as much east of the base, as is equal to the difference between the motion of the top and that of the base of the tower.

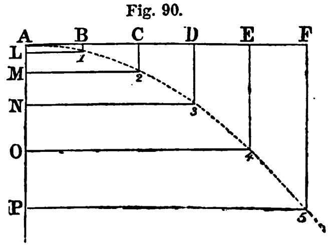
This difference is about half an inch in a fall of 300 feet; a result which has been verified by experiment.

SECTION X.

PROJECTILES.

173. *A body thrown into the air at any angle is called a projectile.* Suppose a ball is fired from A in the horizontal direction AF. If the force of gravity did not act, the ball would move uniformly in the direction AF, passing over equal spaces in equal times. If the ball moved from A to B in one second, it would reach C in two seconds, D in three seconds, and so on. But if the

Fig. 90.



ball were let fall from A without any other force than gravity to act upon it, it would move in a vertical direction, and the spaces AL, LM, MN, etc., described in successive seconds, would be as the numbers 1, 3, 5, 7, etc. If, now, the ball be acted upon by both these forces, it will be found at the close of each second at the extremity of the diagonal of a parallelogram whose sides represent these separate motions; that is, at the end of the first

second it will be found at (1), at the end of the next second at (2), at the end of the third at (3), and so on. *The path thus described is a parabola, for the abscissas vary as the squares of the ordinates.*

If the ball be projected in a direction oblique to the horizon, it may be proved in a similar manner that the path is a parabola.

The horizontal flight of a projectile is called *its range.*

174. Galileo first developed the mathematical theory of projectiles.

According to the theory of Galileo, *the range is greatest when the angle of elevation is* 45°, and is *the same for elevations equally above and below* 45°; as, for example, 60° and 30°.

These conclusions are essentially modified by the resistance of the air. When the velocity of the moving body is small, the deviation from the parabolic path is small; but when the velocity is great, as in the case of a cannon ball, the parabolic theory becomes entirely inapplicable.

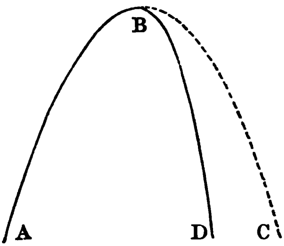
In 1740, Mr. Robins, of England, subjected the theory of projectiles to experiment, and similar but more accurate experiments have since been made by several other persons.

The mode of experimenting with cannon balls, is to suspend the cannon in a horizontal position by means of iron straps attached to a horizontal axis resting on pieces of masonry, so that the gun is free to vibrate like a pendulum, and the observer notes the arc through which the gun recoils at the instant it is fired. In front of the cannon was formerly suspended, in a similar manner, a heavy block of wood, and the amount of vibration communicated to the block afforded the means of computing the velocity of the ball. In modern experiments there has been substituted for the block a mortar of large bore, filled with bags of sand, and suspended in the same manner as the cannon. Such an apparatus was constructed a few years since for the arsenal at Washington.

It is found that a ball, fired with a velocity of 3200 feet per second, so that its range in a vacuum ought to be 20 miles, comes to the ground in less than 2 miles.

With swift motions, the greatest range of a ball corresponds to an elevation of 30°, while for slow motions it is near 45°.

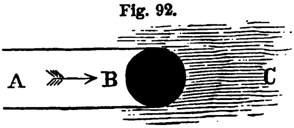
Fig. 91.



The descending branch, BD, of the curve is not symmetrical with the ascending branch, AB, but approaches much nearer to a vertical line.

175. *This discordance between theory and experiment is due to the resistance of the air.* Let B be a cannon ball moving from A to C with a velocity not less than 2000 feet per second. The ball drives before it a column of air from A to B; and, since *air can only flow into a vacuum at the rate of* 1280 *feet per second*, the ball leaves a vacuum behind it. The ball thus experiences the pressure of highly condensed air on one side, without any pressure on the opposite side. This resistance soon reduces the velocity to 1200 feet per second.

Fig. 92.



The resistance of the air modifies the laws of the motions of falling bodies. Since the force of gravity remains constant, while the resistance of the air increases with the velocity of the descending body, this resistance (if the motion be continued) must at length become equal to the weight of the falling body; and, after this takes place, *the falling body will descend with uniform velocity.* There is therefore a limit to the velocity which a body can acquire by falling through the atmosphere. This limit depends upon the dimensions, form, and density of the body. A sphere of lead, one quarter of an inch in diameter, can not, by falling, acquire a velocity exceeding 117 feet per second; a drop of water of the same size can only acquire a velocity of 36 feet per second; and a sphere of cork of the same size a velocity of 18 feet per second.

176. Many familiar facts are explained by this resistance of the air. If a musket, loaded with shot, be discharged vertically upward, the shot may commence their ascent with a velocity of 2000 feet per second, and if there were no resistance they should acquire an equal velocity in falling; but we find that if the falling shot are received upon the naked hand, their force is scarcely sufficient to break the skin.

So, also, the velocity of descending *hail-stones*, and of *drops of rain*, is extremely moderate.

By varying *the shape* of a falling body, we may retard its descent to almost any required extent. By means of a parachute, an instrument in the form of an open umbrella, an aeronaut may descend with safety from a great height.

SECTION XI.

CENTRIFUGAL FORCE.

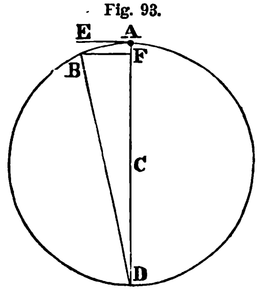
177. If a heavy body be attached to the extremity of a string, and whirled round in a circle, the string will be stretched with a certain force called *centrifugal force*. If a small quantity of mercury, and water colored blue, be put in a glass globe and rapidly revolved, the equator of the globe will be covered with a belt of mercury, having a ring of blue water on each side, and the bottom of the vessel will appear entirely empty.

A pail of water may be whirled over the head so rapidly that the water shall not escape, even when the pail is bottom upward.

This tendency of bodies to fly from the centre of motion is the result of the inertia of matter. A body acted upon by a single impulse tends to move uniformly in a straight line, and it can only be deflected from this direction under the operation of another force.

178. Let A be a ball attached to a string, AC; let C be a fixed point, and ABD the circle in which the ball revolves. Also let AB be the arc which the ball describes in a given time. When the ball was at A, it was moving in the direction of the tangent AE, and it would continue in this direction if it were acted upon by no other force than the first impulse; but we find it deflected into the diagonal AB, and this diagonal is the resultant of two forces represented by AE, AF. Now AE represents the path which the ball would de-

Fig. 93.



scribe under the first impulse, and therefore AF represents the motion impressed upon it by the tension of the string, and which deflects the ball from the tangent to the circle. By the principles of Geometry, B. IV., P. 22, AF : AB :: AB : AD; or AF $=\frac{AB^2}{AD}$; that is, the space AF, or *the centrifugal force, is found by dividing the square of* AB (which represents the velocity of the revolving body) *by* AD, *the diameter of the circle in which the ball revolves.*

If C represents the centrifugal force of a revolving body, V its velocity in feet per second, and R the length of the string in feet, then $C=\frac{V^2}{2R}$.

179. We may *compare the centrifugal force of a body with the force of gravity*, by comparing the spaces through which the body would move in a given time under the operation of these two forces.

Let $W=$the weight of the revolving body, and $g=16$ feet, the space through which W would fall freely in one second. Then we shall have

$$W : C :: g : \frac{V^2}{2R};$$

whence

$$C=\frac{W.V^2}{2R.g};$$

that is, *the centrifugal force of a body revolving in a circle, is found by multiplying its weight by the square of the number of feet which it moves through in one second, and dividing the product by* 16 *times the number of feet in the diameter of the circle it describes.*

180. We may also express the centrifugal force of a revolving body by reference to the number of revolutions made in a given time. Let N represent the number of revolutions, or the fraction of a revolution performed by the body in one second. The circumference of the circle which the body describes will be $2\pi R$. The space through which the body moves in one second, that is, its velocity, is $2\pi R.N$. Hence we have

$$C=\frac{W.(2\pi RN)^2}{2R.g}=\frac{2\pi^2}{g}.W.R.N^2=1.2275\times W\times R.N^2;$$

that is, *to find the centrifugal force of a body revolving in a circle, multiply its weight by the number of feet in the radius of the circle,*

and this product by the square of the number of revolutions, or fraction of a revolution made in one second, and the last product by 1.2275.

Example 1. A ball weighing two pounds is whirled round by a sling 3 feet long, making 4 revolutions per second. What is its centrifugal force? *Ans.* $117\frac{8}{10}$ pounds.

Example 2. If a railway-carriage, weighing 7 tons, moving at the rate of 30 miles per hour, describe a portion of a circle whose radius is 400 yards, calculate its centrifugal force. *Ans.* 791 pounds.

We may easily compute the velocity with which a sling must revolve in order that a stone may be retained in it in all positions, for the centrifugal force must be at least equal to the force of gravity.

Example. If the length of a sling be 2 feet, how many revolutions per second must it make in order that a stone may be retained in it? *Ans.* $\frac{2}{3}$ revolution per second.

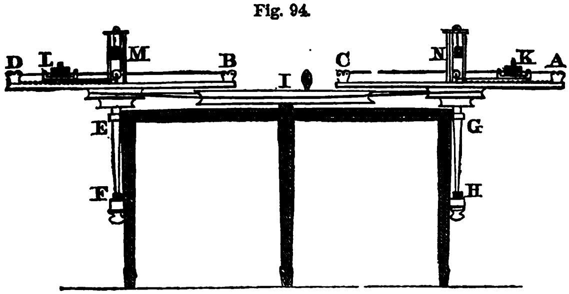
From the preceding principles we see,

1. *If two bodies of equal weight revolve in circles of different radii in the same time, their centrifugal forces will be proportional to the radii.*

2. *If two bodies of equal weight revolve in equal circles, their centrifugal forces will be proportional to the squares of the number of revolutions in a given time.*

181. These conclusions may be verified experimentally by an apparatus called *the whirling table.* This consists of a table with two vertical spindles, EF, GH, to which rotation may be given by means of a wheel and band. To these spindles may be at-

Fig. 94.



tached various objects upon which we wish to try the effects of centrifugal force.

1. To one of the spindles we first secure a circular board, and to its centre attach a metallic ball by a string; the ball does not begin to move as soon as the table is turned, but presently, by friction upon the board, it acquires the same velocity as the board. If we stop the board suddenly, the ball continues to move on, showing the tendency of matter to resist a change of state, whether of rest or motion.

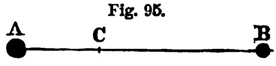
2. If we place one weight on the centre of the board, and several others at different distances, when we revolve the board, the weight most remote from the centre is thrown off first, showing that this had the greatest centrifugal force, while a weight exactly over the centre is not thrown off at all.

3. Two rings, made of thin strips of brass, so as to bend readily when rapidly revolved, bulge out and present the appearance of a spheroid. So, also, a soft spherical body, if rapidly revolved upon an axis, assumes a spheroidal form.

4. We attach to one of the vertical spindles two glass tubes inclined to the horizon at an angle of about 30 degrees. One tube contains a little mercury, is about three fourths filled with water, and a small cork floats on the top. The other tube is also about three fourths filled, partly with oil, and the rest water. Each tube is closely sealed at both ends. When the spindle is at rest, the mercury lies at the bottom of the tube, and the oil floats upon the water. But on turning the spindle, the contents of each tube fly toward the ends which are farthest from the axis of motion, the densest body receding with the greatest force; that is, in one of the tubes the mercury is at the top, and the cork below the water. In the other tube the water occupies the top, and the oil the space below it. This experiment proves that centrifugal force increases with the specific gravity of the body.

5. The centrifugal forces of two bodies revolving in the same time round their common centre of gravity are equal.

Fig. 95.



Let A and B be two balls connected by a rod, and let C be their common centre of gravity. Let the rod be attached to one spindle of the whirling table at C, and the balls be made to whirl round C. The balls will revolve without

producing any pressure upon the axis; showing that the smaller ball, B, gains as much centrifugal force by its longer radius, BC, as the larger ball, A, gains by its superior weight.

But, unless the common centre of gravity coincides with the centre of motion, one ball will tend to drag the other off from the table.

182. These experiments exhibit the general effects of centrifugal force; but, for the purpose of *measuring its exact amount*, an addition is made to the whirling table, called *the bearers.* Each bearer consists of a wooden frame, having two parallel and horizontal brass rods, AC, BD (see *Fig.* 94), upon which a small carriage, K, L, rolls easily, and in this carriage different weights may be placed. To the carriage is attached a cord, which passes over two pulleys, and a weight, M, N, is suspended from the extremity of the cord. When the carriage is made to revolve, it can not recede from the spindle until its centrifugal force becomes greater than the weight attached to the end of the cord. The weight which is lifted becomes therefore a measure of the centrifugal force of the carriage at the instant it begins to move. The two bearers are exactly similar, so that we are able to compare the centrifugal force of the two carriages under a variety of conditions. We may vary the weight of the revolving body; we may vary the distance of the revolving weight from the axis of motion; and we may also vary the velocity of rotation.

183. By this apparatus we may prove,

1. *If unequal weights revolve in equal circles with equal velocities, their centrifugal forces are proportional to their weights.*

Experiment. Make the revolving weights 6 and 12 ounces respectively, and the loads to be lifted 3 and 6 ounces, while the radii of both circles are 5 inches. If the weights are revolved with equal velocities, both loads will rise at the same instant.

2. *If equal weights revolve in the same time in unequal circles, their centrifugal forces will be proportional to the radii of the circles.*

Experiment. Make each of the revolving weights 9 ounces; the radii of the circles 4 and 8 inches; and the loads to be lifted 3 and 6 ounces. If the weights are revolved in the same time, both loads will rise at the same instant.

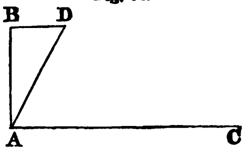
3. *If equal weights revolve in equal circles, their centrifugal forces will be proportional to the squares of their velocities.*

Experiment. Make each of the revolving weights 9 ounces; the radii of the circles 5 inches, while the loads to be lifted are 3 and 12 ounces. Make the velocity of the second weight double that of the first, and both loads will rise at the same instant.

184. We daily meet with examples illustrating the effects of centrifugal force. A horse running round in a circle, experiences a centrifugal force which tends to throw his body outward. To resist this force, he inclines his body toward the centre of the circle. This centrifugal force increases with the velocity. We may compute the proper inclination of the horse toward the centre of the circle in the following manner:

Let the horse be at A, and let him move in a circle of which C is the centre. Draw AB perpendicular to AC, and make its length such that it may be taken to represent the weight of the horse; and parallel to AC, draw BD to represent the centrifugal force. The line AD will represent the proper inclination of the animal, to prevent his falling either outward or inward. The angle BAD may be computed as follows:

Fig. 96.



$$\text{tang. BAD} = \frac{\text{BD}}{\text{BA}} = \frac{\text{C}}{\text{W}} = \frac{\text{V}^2}{2\text{R}g}.$$

If the speed of the horse increases, the centrifugal force will increase, and he must incline more toward the centre of the circle.

Example 1. If a horse run in a circle of 60 feet radius, with a speed of 30 feet per second, how much must he incline from the vertical position in order to prevent falling?

Ans. $\frac{900}{1920} = \frac{15}{32} = .46875 = \text{tang. } 25^\circ.$

Example 2. A ball revolves in a circle whose radius is 1 inch. How many revolutions per second must it make in order that its centrifugal force may be ten times its own weight?

Ans. $\frac{\text{C}}{\text{W}} = 10 = \frac{1.2275}{12} \times \text{N}^2 \therefore \text{N} = 9.89.$

185. The effect of centrifugal force upon a carriage is similar to its effect upon a horse; and, since the carriage is unable to incline at pleasure to counteract this effect, it is liable to be overturned.

Let AB, *Fig.* 97, be a carriage moving rapidly in a circle, and let C be its centre of gravity. Take the line CD to represent the weight of the carriage, and CF its centrifugal force. The resultant of these two forces will be CB. If this resultant meets the ground at any point between the two wheels, the carriage will not be overturned. If this resultant meets the ground at the point B, the whole pressure is thrown upon the wheel B.

Fig. 97.

Fig. 98.

If this resultant meets the ground at a point, G, *Fig.* 98, *outside* of the two wheels, it will tend to overthrow the carriage. Let the force CG be resolved into two forces, one in the direction of CB, and the other CK, perpendicular to CB. The force CB will be resisted by the road, but the force CK will tend to lift the centre of gravity over the wheel. If this force act for a sufficient time to elevate the centre of gravity, so that the line of direction shall fall on B, the carriage will be overturned.

The danger of being overturned depends upon the ratio of BD to CD, or of the distance between the wheels to the height of the centre of gravity of the carriage.

186. On *rail-roads*, where the velocity of motion is very rapid, the centrifugal force of the train in turning a short curve becomes proportionally great; and to counteract its effect, *the outer rail is laid higher than the inner one*, the design being that *the surface of the road shall be perpendicular to the resultant of the centrifugal force and weight of the train.* The direction of this resultant is determined by the proportion

$$C : W :: V^2 : 2R.g.$$

Example. If a rail-road track be five feet in width, how much should the outer rail be higher than the inner one, on a curve of 1000 feet radius, for a velocity of 40 feet per second?

$C : W :: V^2 : 2Rg :: 1600 : 32000 :: 1 : 20.$ *Ans.* 3 inches.

187. If a rod be inserted in a solid body, and the body be made to turn rapidly round this rod as an axis, each particle of the body, revolving in a circle, will acquire a centrifugal force which will be proportional to its distance from the axis.

If the body be in the form of a ring, and the axis passes

through its centre perpendicular to the plane of the ring, the centrifugal forces exerted by all the particles on the axis will neutralize each other, and the axis will suffer no strain in consequence of the centrifugal force.

The same would be true of a flat, circular plate of uniform thickness and density. Also of a cylinder, a cone, a sphere or spheroid, when made to revolve upon its geometrical axis.

If a rectangular plate, ABCD, be made to revolve round a line, MN, passing through its centre of gravity, G, but not parallel to either side of the rectangle, the centrifugal forces will not be in equilibrium. Through any point, F, draw the line EFH, perpendicular to MN. This line will be divided into unequal parts at F, and the centrifugal force of the particles between F and H will be greater than that of the particles between E and F. The same will be true of all lines drawn perpendicular to MN above the point G; and the combined effect of all the centrifugal forces acting above the point G, will have a resultant directed toward the side of the angle B. For the same reason, the centrifugal forces of that part of the plate below G, will have a resultant directed toward the side of the angle D, and this resultant will be equal to the former resultant. These two forces form a couple, and *tend to turn the axis of revolution toward the position* KL.

Fig. 99.

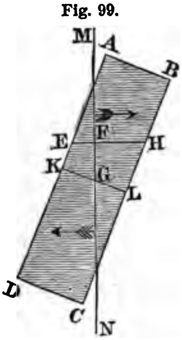
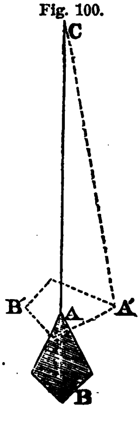


Fig. 100.



188. *Experiments.* Let a body, AB, in the form of a cylinder or cone, be suspended by a string from a fixed point, C, and let a rapid rotary motion be given to it. This rotary motion will at first take place round a line passing vertically through the point of support. If this line does not coincide perfectly with the axis of the cylinder, the rod will throw itself into a position nearly at right angles to the string; that is, it will revolve round an axis passing through its centre and perpendicular to its length.

This effect takes place in spite of the opposing influence of the weight of the body, which tends

to bring the centre of gravity vertically under the point to which the string is attached.

If an oblate spheroid be suspended with its longest axis in a vertical position, when it rotates rapidly, it will assume a position in which the shorter axis is vertical.

If a flat, circular disc be suspended so that its plane is in a vertical position, when it rotates rapidly, it will rise and turn over, assuming a position in which its plane is horizontal.

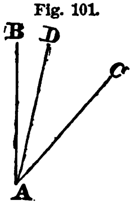
In each of these cases, *the axis about which the body tends to revolve is the shortest axis of the figure.*

If a metallic chain, the ends of which are united, be suspended by a string and put in rapid rotation, the chain will gradually open and assume the form of a circle, the plane of which is horizontal. In this experiment, it is obvious that the centrifugal force tends to cause each link of the chain to recede as far as possible from the axis of motion.

189. COMPOSITION OF ROTARY MOTION.

We have seen, *Art.* 52, that when two impulsive forces act simultaneously upon a body, their combined effect may be represented by a single force which we call the resultant. Rotary motions may be compounded in a similar manner, according to the following theorem:

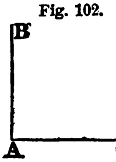
Fig. 101.



If a body revolve freely round the axis AB, *with the angular velocity* V, *and if a force be impressed upon it which would make it revolve about the axis* AC *with an angular velocity* V′, *then the body will not revolve about either of the axes* AB, AC, *but about a third axis,* AD, *situated in the plane* BAC, *and the angle* BAC *will be divided so that sin.* BAD : *sin.* CAD :: V′ : V.

From this theorem it follows, that *if a uniform force act upon a body, tending to give it a motion of rotation about an axis which is always perpendicular to the axis about which it is at each instant revolving, and always in the plane* BAC, *the axis of rotation will have a uniform motion in space, from the position* AB *toward* AC.

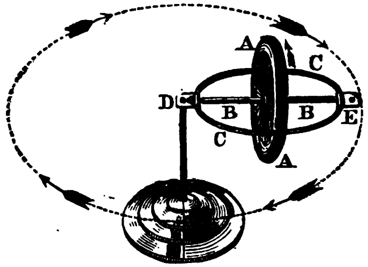
Fig. 102.



190. This principle is beautifully exemplified in an instrument

called *the Gyroscope.* The gyroscope consists of a heavy brass wheel, AA, having a steel axis, BB, and mounted in a brass ring, CC, which is supported on one side, D, in such a manner that the opposite end of the axis, E, is capable of free motion in a vertical plane, and the ring, with its contained wheel, is capable of free motion about a vertical axis. If the wheel be put in rapid rotation about its axis when in a horizontal position, and only one end, D, of the axis be supported, gravity tends to pull the other end of the axis, E, downward; that is, *the wheel tends to turn about an axis perpendicular to the former.* The axis of the wheel will accordingly commence turning in a horizontal plane around the point of support; and the slower is the rotation of the wheel about its axis, the more rapid will be the motion of this axis in the horizontal plane, because the motion which gravity tends to impress upon the wheel is constant, and the slower is the rotation of the wheel, the greater is the ratio which the former motion bears to the latter.

Fig. 103.

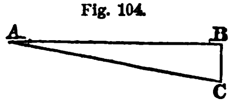


This second motion of the wheel leads to a very singular consequence. The wheel was first put in rotation about *a horizontal axis*, and now the wheel (including its supporting ring) turns also about *a vertical axis.* According to the theorem already stated, the resultant of these two rotations is a rotation about an axis inclined upward from the horizontal position. *The horizontal axis tends to incline upward* with a force depending upon the velocity of the new motion about the vertical axis. When the latter motion bears a certain ratio to the first motion of rotation, the tendency of the wheel upward is just equal to the attraction of gravity downward, and the axis of the wheel remains in a horizontal position. We thus have the seeming paradox of *a heavy wheel steadily revolving about a horizontal axis, while only one end of the axis has any material support.* If we increase the rate of motion about the vertical axis, the unsupported end of the axis of the wheel immediately inclines upward at an angle of

30, 60, or more degrees, depending upon the ratio of the two motions. *If the ring be restrained from revolving about the vertical axis, the unsupported side immediately falls*, as it would do if the wheel did not rotate.

191. The gyroscope illustrates another important principle. If, when the wheel is in rapid rotation, it be held in the hand by means of the ring, and we attempt to incline it in any direction, so as to change the position of the plane of rotation, it will oppose a sensible resistance to such change. This principle is known by the name of *persistence in the plane of rotation*, and may be thus explained. A body moving in a straight line, on account of its inertia, opposes resistance to any force which attempts to turn it out of that line; so, also, a body revolving in a circle opposes resistance to any force which attempts to turn it out of the plane of that circle. Let AB represent the force with which a particle is impelled in its rotation, and let BC represent another force acting at right angles to the plane of rotation. Under the joint action of both forces, the particle will move in the line AC, and, unless the force BC be considerable in comparison with the force of rotation, the plane of rotation will be but slightly changed. But in the experiment with the gyroscope, the mass of the wheel is considerable, and it is made to revolve with great velocity; that is, it has great momentum, and it requires a corresponding force to turn it sensibly out of the first plane of rotation.

Fig. 104.



192. The principle of the composition of rotary motions is also illustrated by *the common spinning-top*, with such modification as arises from its entire freedom of movement.

A solid of revolution is a solid formed by the revolution of a plane figure about a fixed axis, as a cone by the revolution of a triangle, etc.

A spinning-top has the form of *a solid of revolution*. The end upon which it spins should be a little rounded, and approach to the form of a hemisphere. When the axis of the top is in a vertical position, the line of direction falls within the base; but, unless the top rotate, the position is one of *unstable equilibrium*, and the top is liable any moment to fall. If it revolve upon its axis when in a vertical position, the centrifugal forces on the

opposite sides, being exactly balanced, have no tendency to disturb the position of the axis; but if the axis inclines a little from the vertical position, gravity tends to bring the top down; that is, *the top tends to turn about a horizontal axis passing through the point of support.* But the top is already rotating about an axis nearly vertical. From the composition of these two rotary motions, according to the theorem before stated, *Art.* 189, the axis of the top inclines in a direction at right angles to that in which gravity tends to carry it, and, by the rolling of the rounded end upon the table, *the point of support is carried in a curve exterior to the point vertically under the centre of gravity;* and *the centrifugal force thus generated throws the centre of gravity outward,* which tends to bring the geometrical axis nearer to the vertical position, counteracting the influence of gravity which tends to pull it down, and, if the velocity of rotation be sufficient, it will restore the axis of the top to a vertical position.

193. In order, however, that this effect may be produced, *there must be a certain amount of friction* to prevent the point from sliding upon the table, otherwise the top will be tripped up, as happens when a top with a steel point is revolved upon a perfectly hard surface. If the top terminate in a very sharp point, the top, by the rolling of its point upon the table, can not travel along the table; that is, the point remains almost stationary; and when the top inclines a little from the vertical position, the centre of gravity moves in a circle about a vertical line passing through the point; so that *the effect of centrifugal force is exerted in a direction from the point, and throws the top down.*

Accordingly we find that *a top with a perfectly sharp point can not be made to spin;* and if the end (although rounded) be so confined that it can not travel, *the centre of gravity will move in a circle exterior to the line which passes vertically through the point of support,* and the centrifugal force, being exerted in a direction *from* the point, tends to throw the top down.

SECTION XII.

THE PENDULUM.

194. *A simple pendulum* is a particle of matter suspended by a right line void of weight, and oscillating about a fixed point by the force of gravity.

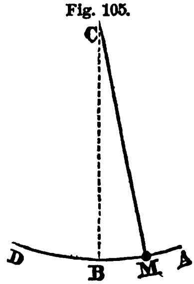
A compound pendulum consists of a solid body suspended by a line, and oscillating freely about a fixed point.

The point about which the pendulum oscillates is called *the centre of suspension.*

A vibration of a pendulum is its motion from a state of rest at the highest point on one side of the vertical position, to the highest point on the other side.

195. *Of simple pendulums.* Suppose the body M, suspended by a fine string from a fixed point, C, to commence its vibration from A in a small circular arc. It will reach the lowest point, B, with a velocity due to the height of A above B, and will afterward move with a gradually decreasing velocity until it reaches D, at an equal height above B, from which it will again descend toward B, and it would thus continue vibrating to and fro forever if its motion were not checked by friction, resistance of the air, etc.

Fig. 105.



It may be proved that if a pendulum vibrate in a small circular arc, *the time of one vibration is to the time of a body's falling freely down half the length of the pendulum, as the circumference of a circle is to its diameter;* that is, representing the length of the pendulum by L, and the time of one vibration by T, we have

$$T : \sqrt{\frac{L}{2g}} :: \pi : 1;$$

whence $$T = \pi\sqrt{\frac{L}{2g}}.$$

As the value of T in this equation depends solely on the force of gravity and the length of the pendulum, it appears that for small arcs, the time of one vibration is independent of the length

of the arc of vibration. This principle was discovered by Galileo about the year 1585.

From the above equation, we also see that *the times of vibration of different pendulums vary as the square roots of their lengths.*

The length of a half second's pendulum is		9.77	inches.
"	second's	" 39.10	"
"	two seconds'	" 156.40	"

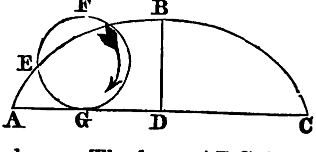
Example. What must be the length of a pendulum which shall oscillate ten times in a second? *Ans.* 0.391 inch.

196. *The time of vibration increases slightly with the length of the arc.* Suppose we have two pendulums of the same length. If we make them oscillate through very unequal arcs, the times of vibration will differ sensibly, and the one which moves in the smallest arc will gain upon the other; but if the arcs are nearly equal, the difference in the times of vibration can only be detected after a long interval.

When the arc of vibration is 1° on each side of the vertical, the daily retardation, as compared with a vibration in an infinitely small arc, is $1\frac{2}{3}$ seconds. When the arc is 2°, the loss is $6\frac{2}{3}$ seconds; for 3°, it is 15 seconds; for 4°, it is $26\frac{2}{3}$ seconds; for 5°, it is $41\frac{2}{3}$ seconds; for 6°, it is 60 seconds, etc. These numbers are represented by the formula, the daily retardation $=\frac{5}{3}D^2$, where $D=$the number of degrees the pendulum describes on each side of the vertical.

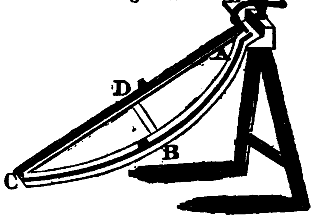
197. The inconvenience resulting from the inequality of the times of vibration in circular arcs, may be obviated by the use of a curve called *the cycloid.* The cycloid, ABC, is a curve generated by a point in the circumference of a circle, EFG, rolling in a straight line, ADC, on a plane. The base, ADC, is equal to the circumference of the generating circle EFG, and BD is equal to its diameter.

Fig. 106.



The cycloid is the curve of quickest descent from one point to another. Let ABC, *Fig.* 107, be an arc of

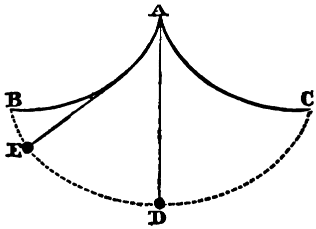
Fig. 107.



a cycloid. A ball will descend from A to C on the cycloidal arc ABC, quicker than it will descend on the straight line ADC, or upon any other line. *It will also describe the entire length of the cycloidal arc* ABC, *in the same time it would descend to* C *through any portion of the arc, as* BC. Hence, if a pendulum could be made to vibrate in a cycloidal arc, all the vibrations would be made in equal times.

A pendulum may be made to vibrate in a cycloidal arc, by using a flexible line, AD, and securing on each side of it a semi-cycloidal plate, AB, AC, so that, as the ball ascends to the highest point, B, the string, AE, shall wind round the semi-cycloid AB, and shall unwind from it as the ball descends to the lowest point, D.

Fig. 108.



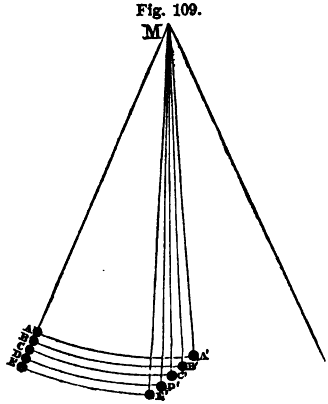
Attempts have been made to apply this pendulum to clocks, but there are practical difficulties which have hitherto rendered this application useless.

The pendulums of astronomical clocks are always made to vibrate in small circular arcs.

198. *Of compound pendulums.*

Let A, B, C, D, E be several small balls suspended by independent strings from the point M. If they are all disengaged at the same instant from the line ME, the ball A will oscillate more rapidly than the ball B; B will oscillate more rapid-idly than C, and so on; so that, after a time, they will have the positions A′, B′, C′, D′, E′. If, now, these balls are all attached to the same wire, so as to be compelled to keep in the same straight line, the balls which are nearest to the point of suspension will tend to accelerate the motion of those which are more

Fig. 109.



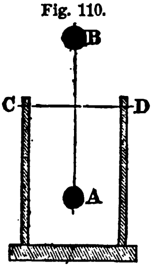
distant, while those which are most distant will tend to retard the motion of those which are nearer. There will therefore be *a certain point which will separate those which are moving slower than their natural rate, from those which are moving faster than their natural rate;* and a ball placed at this point would vibrate in the same time that it would if it were not connected with any other. *This point is called the centre of oscillation of the system of balls.*

The centre of oscillation of a pendulum may therefore be defined to be such a point that, if all the matter of the pendulum were collected in it, the time of vibration would remain unchanged. This point is generally *below the centre of gravity.*

199. *By the length of a compound pendulum, is to be understood the distance between the point of suspension and its centre of oscillation.*

If a cylindrical bar be suspended by one of its extremities so as to vibrate like a pendulum, the distance of the centre of oscillation from the point of suspension is two thirds the length of the bar. The centre of oscillation may be entirely *beyond the pendulum.* This is seen in *the metronome,* an instrument employed to measure time in music.

Fig. 110.



It consists of two balls, A, B, attached to a short rod, and mounted on a horizontal axis, CD, the balls being capable of adjustment by screws. If both balls are placed at equal distances from the axis, the rod will not oscillate at all; if their distances from the axis are slightly unequal, the rod will oscillate very slowly; and we may vary the time of vibration at pleasure, by changing the distance of either ball from the axis. Thus an instrument whose extreme length is only 6 inches, may be made to vibrate once in 1 second or 2 seconds at pleasure.

The centre of oscillation and the centre of suspension are convertible points; that is, if a pendulum be inverted and suspended by its centre of oscillation, its former point of suspension will become its new centre of oscillation, and the time of vibration will remain unchanged.

This principle enables us to determine mechanically the cen-

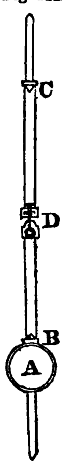
tre of oscillation, and hence the length of a compound pendulum.

A second's pendulum is one which makes one vibration per second, or 86,400 vibrations in a day.

200. *Three principal methods* have been practiced for determining the length of the second's pendulum.

The apparatus employed by Borda consisted of a sphere of platinum about 1½ inches in diameter, weighing somewhat over one pound, and suspended by a slender platinum wire. The extreme length from the point of support to the bottom of the sphere was measured, and the distance between the centres of oscillation and suspension was computed by mathematical principles. Other methods of observation are now considered preferable to this.

Fig. 111.



The pendulum employed by Kater consists of a brass bar 1½ inches wide, and one eighth of an inch thick, in which are inserted two knife-edges, B and C, about 39 inches apart, so that the pendulum can vibrate on either of them at pleasure. A small weight, D, is attached to the bar near its centre, and is adjusted by means of a screw, so that the position of the centre of gravity of the bar may be easily changed. By repeated trials, the weight is so adjusted that the time of one vibration is found to be the same when the pendulum is suspended from either knife-edge, so that each gives the centre of oscillation belonging to the other. The distance between the two knife-edges is then measured, and this is regarded as the length of the pendulum.

Bailey's pendulum is a slight modification of Kater's. It consists of a plain straight bar of brass, 2 inches wide, 62 inches long, and three eighths of an inch thick. One knife-edge is placed 5 inches from one end of the bar, and the second 39.1 inches from the first. The pendulum is then adjusted by filing off from either end of the bar until it oscillates in equal times in either position. If the pendulum does not make exactly one vibration per second, we have but to observe the precise time of one vibration, from which we can readily compute the length of the second's pendulum. Bailey's pendulum has this advantage over Kater's, that its adjustments are not

liable to be deranged by traveling, and therefore it is better adapted to use in a scientific expedition.

201. Expeditions have been made to almost every part of the globe for the purpose of determining the length of the second's pendulum. The following are among the results of these experiments:

Length of the second's pendulum at the equator,	39.01	inches.
" New York,	39.10	"
" London,	39.14	"
" Spitzbergen,	39.21	"

Since the second's pendulum is longer near the pole than at the equator, a pendulum of given length would vibrate in less time at the pole than at the equator; that is, *the earth's attraction must be stronger at the pole than at the equator.* Thus the pendulum enables us to determine the variation of the force of gravity on different parts of the earth's surface; and *hence we are able to compute the figure of the earth.*

202. Since the pendulum affords a measure of the intensity of the force of gravity, it supplies the means of computing *the height from which a body falling freely would descend in a second.* This method is susceptible of much greater accuracy than that of Atwood's machine.

We have seen that $$T=\pi\sqrt{\frac{L}{2g}};$$

whence $$L=\frac{2gT^2}{\pi^2};$$

and if $T=1$ second,

$$g=\frac{\pi^2}{2}.L.$$

Example. If the length of the second's pendulum at New York is 39.1 inches, through what space will a body fall in one second? *Ans.* 192.95 inches.

203. The most important application of the pendulum is to *the measurement of time.* Before the invention of the pendulum, the means employed for measuring time were extremely rude. Time was measured by the hour-glass, by the descent of a column of water which discharged itself by an aperture in a vessel, etc.

The uniformity in the times of vibration of a pendulum was

noticed by Galileo about the year 1585, but the first pendulum clock was made by Huygens in 1657. The length of a pendulum changes with every variation of temperature. As the temperature rises, the pendulum becomes longer, and requires a longer time for its vibration. Clocks, therefore, go slower in summer and faster in winter. With an iron pendulum, a difference of temperature of 25° makes a difference of 6 seconds a day in the rate of the clock. When extreme accuracy is required, as in astronomical observations, some expedient must be adopted to counteract this error. Pendulums thus constructed are called *compensation pendulums.* All compensation pendulums depend upon the combination of two substances which expand unequally for the same change of temperature; and these substances are so combined that, while *the expansion of one increases the distance of the centre of oscillation from the point of suspension, the expansion of the other has the contrary effect;* and the proportions of the two substances should be so adjusted, that these two effects are exactly equal, so that the centre of oscillation may be maintained at the same distance from the point of suspension.

204. Compensation pendulums are commonly made by combining mercury and steel, or brass and steel. Mercury expands 14 times as much as steel for a given change of temperature. A pendulum rod of steel may therefore be compensated by substituting for the usual bob, a glass cylinder, FH, filled to the height of about 6 inches with mercury.

Fig. 112.

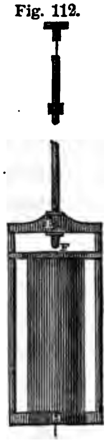
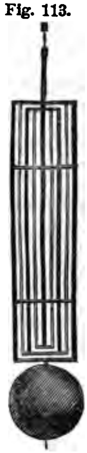


Fig. 113.



The expansion of brass is to that of steel as 100 to 61. A compensation pendulum may therefore be made of these metals; but, since the difference of expansion is so small, it requires a long bar of brass to effect this object. The bar is therefore divided into several parts, arranged in parallel lines, presenting some resemblance to a gridiron, and is hence commonly called *the gridiron pendulum.*

205. The pendulum is extensively used as *a standard of measures of length.* The standards of length formerly employed were of

the rudest kind. Among them we find the digit, or finger, hand's breadth, cubit, foot, pace, etc. Henry VII.'s arm was for a long time the standard in England.

All such standards are very inaccurate and uncertain.

A standard of measures should be invariable and indestructible. Such is the pendulum, vibrating seconds for any given place; and this has been chosen as the standard of length both in England and the United States. The length of the second's pendulum at London was declared by Parliament in 1824 to be 39.1393 inches. Our own government has adopted the same standard.

206. In 1790, the French government adopted for their standard of length *the metre*, which was declared to be *the ten millionth part of a quadrant of the globe.* A considerable portion of a quadrant of the globe has actually been measured, and its entire length has been computed with great accuracy. The metre is found to be 39.37 English inches. The metre is divided into tenths, hundredths, etc., designated by the Latin numerals, and called decimetre, centimetre, and millimetre. We have also multiples by ten, one hundred, etc., designated by Greek numerals, and called decametre, kilometre, myriametre, etc.

The advantages of the French standard are,

1. It is invariable and indestructible.
2. Its length is known with great accuracy.
3. It is adapted for the use of *all nations*, because *it does not belong to any one nation exclusively*. The English standard of length is *a local standard*, because the second's pendulum at London has a different length from the second's pendulum at Paris.

No serious objection has been urged against the general adoption of the French standard, except that which arises from the reluctance of people to abandon long-established habits.

SECTION XIII.

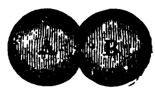
COLLISION OF BODIES.

207. The effects of collision are different for *elastic* and for *inelastic* bodies. *Elastic bodies are such as, when compressed, restore themselves to their former state;* as, for example, balls of ivory or steel.

Inelastic bodies are such as, if compressed, do not return to their former state, as balls of soft clay or putty.

Elastic bodies must be so constituted as to allow some of their atoms to be brought suddenly closer together than usual, without permanently disturbing their position. Thus, if two ivory balls, A, B, be struck together, we find that the two spheres touch each other in a surface of considerable extent, proving that the position of the particles is temporarily disturbed; nevertheless, they return almost immediately to their former position.

Fig. 114.



208. Atmospheric air may be condensed, and also expanded to an almost indefinite extent. Air of the usual density has actually been rarefied 5580 times, and it has been condensed 1500 times; that is, the densest air which has actually been obtained, was 8 million times as dense as the rarest. If we suppose the particles of the densest air to have been actually in contact with each other, *the distance between the particles of the rarest air must have been* 200 *times the diameter of a particle.*

It is evident, therefore, that atmospheric air consists of particles maintained at a distance from each other, under the operation of forces which act like springs, which may be compressed, but recover themselves as soon as the compressing force ceases; and it is probable that all elastic bodies have a similar constitution.

209. *A body is perfectly elastic when the force of restitution is equal to that of compression;* that is, if it impinges perpendicularly on a fixed plane, it will rebound from the plane with equal velocity. Common air is perfectly elastic. Most bodies are imperfectly elastic. Glass, ivory, marble, and steel are highly elastic, but not perfectly so; brass and lead have less elasticity, and

soft clay still less; but there is no solid body entirely void of elasticity.

In an imperfectly elastic body, the velocity of recoil is less than the velocity of approach in a constant ratio; and this constant ratio is called the *coefficient of elasticity.*

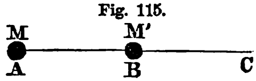
We may comprehend all bodies in one statement, by saying that there is a coefficient of elasticity proper to each body in nature; that when this coefficient is unity, the body is perfectly elastic; that when it is zero, the body is perfectly inelastic; and when it has any intermediate value, the body is imperfectly elastic. The coefficient of elasticity for glass is .94, ivory .81, marble and steel .79, while that of lead is only .20.

India-rubber allows a much greater degree of compression than either of these substances, but its coefficient of elasticity is less than .50.

210. *Inelastic bodies.*

1. Suppose a mass of matter, M, moving in the direction AB, with a velocity V, to encounter another mass, M′, in a state of *rest.* After impact, *the two masses will move on together with a common velocity.* Now whatever force is acquired by M′ must be lost by M, and therefore the momentum of the united masses after impact must be equal to the momentum of the mass M before impact. The momentum of the mass M before impact was represented by M.V.

Fig. 115.



If v represents the velocity of the united mass after collision, the momentum after collision will be $(M+M')v$.

Hence we have $M.V=(M+M')v$;

that is, the mass M multiplied by its original velocity, is equal to the united masses multiplied by their subsequent velocity.

Also we have $$v=\frac{M.V}{M+M'}.$$

2. Suppose the body M′ to be moving in the *same direction* as the body M, but with a velocity, V′, *less* than V, so that the body M overtakes the body M′. After collision, *the two bodies are found to move on together with a common velocity.* The momentum of the united masses after collision, must be the same as before collision. Hence

$$M.V+M'.V'=(M+M')v,$$

or $$v=\frac{M.V+M'.V'}{M+M'}.$$

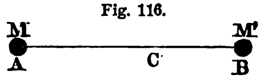
Whatever momentum one of the bodies gains, the other loses. This results from the third law of motion: "Action and reaction are equal, and in contrary directions." The term action in this case signifies the effect which the striking body produces in imparting momentum to the body struck; reaction denotes the effect which the body struck produces in depriving the striking body of a part of its momentum.

Example. If a boat weighing 1000 pounds, and rowed at the rate of 15 feet per second, be connected by a rope with another boat weighing 2000 pounds, and rowed in the same direction at the rate of 10 feet per second, required the rate per second at which they will move together.

Ans. $\frac{1000\times15+2000\times10}{1000+2000}=11\tfrac{2}{3}$ feet.

211. 3. Suppose the two bodies M and M′ to be moving *toward each other*, the momentum of M being greater than that of M′. By collision, the momentum of M′ will destroy as much of the momentum of M as is equal to its own amount, and *the two bodies will move on together with a common velocity.* The momentum of the united mass after collision, is the difference of their momenta before collision. Hence

Fig. 116.



$$M.V-M'.V'=(M+M')v,$$

or $$v=\frac{M.V-M'.V'}{M+M'}.$$

If two equal inelastic bodies, moving with equal velocities in opposite directions, meet, both bodies will remain at rest after collision.

If two equal railway trains, moving in contrary directions at 25 miles an hour, encounter each other, the shock will be the same as if one of them (being at rest) were struck by the other moving at the rate of 50 miles an hour.

212. *Perfectly elastic bodies.*

If a body be perfectly elastic, *the force of restitution will be equal to that of compression;* and the body will rebound with the same force as that with which it struck.

If an ivory ball be dropped upon a hard level surface, it will

rise nearly to the height from which it was dropped. It will not rise exactly to the same height, partly from the want of perfect elasticity, and partly from the resistance of the air.

Fig. 117.

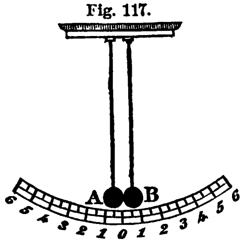


Fig. 117 represents a convenient arrangement for experimenting on elastic bodies. The balls A and B are suspended side by side, by strings of the same length, and a graduated scale measures the arc through which each of the bodies is made to move.

213. 1. *If one perfectly elastic body strikes upon another equal to it at rest, the first will be brought to rest, and the second will move on with the original velocity of the first.*

For the second body, B, destroys half the velocity of A during the act of compression; and since, in elastic bodies, the force of restitution is equal to that of compression, the body B destroys an equal amount of force during the act of restitution; that is, it destroys all the velocity of A.

Also the body B acquires half the velocity of A during the act of compression; and, during the act of restitution, the body A communicates an equal amount of velocity; that is, B moves on with the original velocity of A.

If several equal elastic balls be arranged in a straight line, and the first be made to impinge upon the second, and so on, the last will move on with the original velocity of the first ball, while all the others will come to rest.

2. *If one elastic body strikes upon another equal body moving with a less velocity in the same direction, each will move after impact with the previous velocity of the other body.*

For, during the act of compression, the body A loses half the excess of its velocity above that of B; and during the act of restitution, it loses as much more; that is, it moves on with the previous velocity of B.

Also, during the act of compression, B gains half the excess of A's velocity above B's; and during the act of restitution, it gains as much more; that is, it moves on with the previous velocity of A.

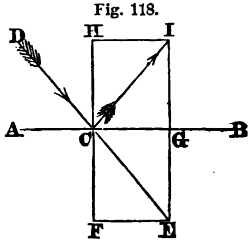
3. *If two equal elastic bodies, moving in opposite directions, meet,*

each will be reflected back with the original velocity of the other body.

214. *When a perfectly elastic body impinges upon a perfectly smooth plane, it is reflected, making the angle of reflection equal to the angle of incidence.*

Let AB be a smooth surface, and let an elastic body strike it at C, having moved in the direction DC. The force of the impact at C, being represented by CE, may be resolved into two forces, CF perpendicular to AB, and CG parallel to AB. In consequence of its elasticity, the body will rise from the plane with a velocity represented by CF, and its velocity in the direction of the plane will be represented by CG. Take CH equal to CF, and complete the parallelogram CGIH. The diagonal CI will represent the direction in which the body will move after impact; but, since the parallelogram CGIH is equal to the parallelogram CGEF, the angle which CI forms with the surface AB, is equal to the angle which DC forms with the same surface.

Fig. 118.



If the body be *imperfectly elastic*, the velocity CG, in the direction of the plane, will not be changed by impact, since the body and plane are supposed to be perfectly smooth; but the velocity in the direction perpendicular to the plane will be less than CF; hence the angle of reflection, HCI, will be greater than the angle of incidence, HCD.

If the body be *perfectly inelastic*, the velocity CF, perpendicular to the plane, will be entirely destroyed by the plane, and there will be no vertical velocity after impact, while the velocity CG, in the direction of the plane, remains unchanged. Hence the body will slide along the plane with a velocity represented by CG.

BOOK SECOND.

HYDROSTATICS AND HYDRODYNAMICS.

SECTION I.

NATURE OF LIQUIDS.

215. *That part of Natural Philosophy which treats of the equilibrium of liquids, is called Hydrostatics; that part which treats of their motion, is called Hydrodynamics.*

There are various phenomena which indicate that between the particles which compose the mass of a body, there exist *attractive and repulsive forces,* whose action extends only to distances scarcely perceptible to the senses.

It is attraction which holds the particles of a solid body together, which enables it to resist fracture or a change of figure.

The attraction between the particles of a liquid is seen in the tendency to form into spherical drops, a sphere being that body which has the greatest volume with a given surface.

All bodies are capable of being compressed, but they resist compression with a certain force; and many of them recover their former volume when the compressing force is removed. This indicates a repulsive force existing between the atoms of the body.

216. *When the attraction prevails greatly over the repulsion,* the particles are held firmly together, and the body is called *a solid. When the forces are equal,* the particles will yield to the slightest force, and the body is called *a liquid. When the repulsive exceed the attractive forces,* the particles of the body tend to separate from each other, and they require the application of some external force to keep them together. The body is then called *a gas.*

By the combination of mechanical pressure and cold, several of the gases have been reduced to the liquid state, and it is probable that all the gases are capable of this change. Some of them have been reduced to the solid state, which shows the attraction

of cohesion existing among their particles. We hence infer that beyond the sphere of cohesion, there is a sphere of repulsion between the atoms of gaseous bodies. When the particles of a gas are brought into such close contact as to be within the sphere of cohesion, they form a liquid or a solid body.

The mutual repulsion prevailing among the particles of bodies is by some ascribed to the agency of *heat.*

In a lump of ice, the attraction of cohesion between the particles predominates over the influence of the repulsion; but if heat be applied, the force of cohesion is weakened, and at length the force of repulsion becomes nearly equal to it, and the solid is converted into a liquid. If heat be still applied to this liquid, it will expand, and, after a time, the repulsive force between the particles becomes so great that, in spite of their weight, they disperse into a vapor, capable of expanding without limit.

217. *Compressibility of liquids.*

It was formerly believed that liquids were *incompressible,* but it is now known that they may be compressed in a slight degree. This has been proved by various experiments, but the most elegant method is by means of Œrsted's apparatus. This consists of a strong glass cylinder, AB, filled with water, upon which pressure can be exerted by means of a piston driven by a screw, C. When the screw is turned, and pressure is exerted on the liquid, the liquid contracts; but, at the same time, the glass vessel expands, and thus the phenomena are rendered exceedingly complicated. To obviate this difficulty, Œrsted invented *a gauge.* This gauge consists of a glass bulb, D, about 5 inches long, and $\frac{3}{4}$ inch in diameter, with which is connected a fine tube 6 inches long, and terminating in a small open cup, F. To the tube is attached a scale E, graduated into equal parts. The bulb and tube are filled with water, and in the cup is placed a small globule of mercury. By the side of this tube is a second glass tube, G, about 5 inches long and $\frac{1}{4}$ inch in diameter, which is open at one end, the open end being downward. The pressure exerted on the water is measured by the compression of the air confined in this tube.

Fig. 119.

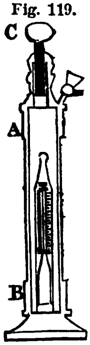
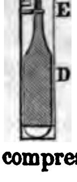


Fig. 120.



When the gauge is put in the cylinder (which should be previously filled with water), and pressure is exerted by the screw, the water in the bulb, as well as that in the cylinder, is compressed; but the glass which forms the bulb, being pressed both internally and externally, is but little affected by the pressure. With each revolution of the screw, the mercury is forced down the small tube several divisions, while the degree of pressure exerted is shown by the contraction of the air in the inverted tube. We thus find not only that water may be compressed, but we are able accurately to measure the degree of compression. This compression amounts to one part in 22,000 for a pressure of 15 pounds on a square inch, and the compression appears to be proportional to the pressure.

SECTION II.

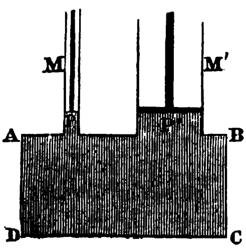
EQUILIBRIUM AND PRESSURE OF LIQUIDS.

218. *Equal transmission of pressure.*

Since the particles of a liquid move among each other with perfect freedom, it follows that *liquids must transmit pressure equally in every direction.*

Let a close vessel be filled with a liquid which we will suppose to have no weight. If an aperture of the size of one square inch be made in one side of this vessel, and a piston be fitted to the aperture, and a pressure of one pound be exerted upon the piston, each square inch upon every side of the vessel must sustain an equal pressure. The consequences of this principle are very remarkable. Let ABCD be a close vessel filled with water. Let M be a cylinder, having a piston, P, the area of whose base is one square inch; and let M′ be a second cylinder, having a piston, P′, the area of whose base is ten square inches. A pressure of one pound acting on the piston P, will produce a pressure of one pound on *each* square inch of P′; that is, it will

Fig. 121.

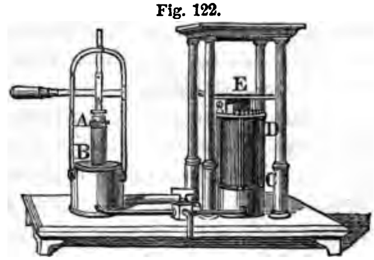


produce a total pressure of 10 pounds on the piston P′; and a weight of one pound resting on P, would support a weight of 10 pounds resting on P′.

219. This case is analogous to that of a lever with unequal arms. If the piston P descend one inch, one cubic inch of water will be expelled from the cylinder M; and since the vessel ABCD was supposed to be entirely full, the piston P′ will be forced upward. But, since the area of M′ is 10 times as great as that of M, the height to which P′ will rise will be only $\frac{1}{10}$ of an inch. In order to raise P′ one inch, P must be depressed 10 inches; that is, a power of one pound acting through a space of 10 inches, balances a weight of 10 pounds acting through one inch, which is precisely what takes place with a lever of unequal arms.

220. There is a machine in common use which is founded on this principle. It is called *the hydraulic press.* A large and a small metallic cylinder are made to communicate freely with each other by a pipe. A piston, playing through a water-tight collar, is adapted to the small cylinder, AB. At the bottom of this cylinder is a valve which opens upward, and communicates by means of a pipe with a reservoir of water. The large cylinder, CD, is also provided with a strong piston moving in a water-tight collar, and carrying a strong head-plate, E, which works in a frame, so as to move directly toward another plate which is stationary. When the large piston is forced upward, any object placed between the two plates is subjected to pressure.

Fig. 122.



Suppose both pistons to be at the bottom of their respective cylinders. If the small piston be elevated, the water from the reservoir will follow it and fill the small cylinder; if then the piston be depressed, the water in the cylinder will be prevented from returning to the reservoir by a valve opening upward, and it is forced through the connecting tube into the large cylinder. A second valve prevents the return of the water from the large

to the small cylinder. Thus, at each stroke of the piston, a quantity of water equal to the capacity of the small cylinder, is forced into the large cylinder. If the area of a section of the large piston be 30 times that of the small one, a pressure of one pound on the small piston will produce a pressure of 30 pounds on the large piston. The power of the machine is still farther augmented by a lever which works the small piston. If the increase of power from the lever be 6 fold, then a force of 1 pound on the lever exerts a force of 180 pounds on the large piston.

When it is desired to release the object subjected to the action of the press, a screw is turned which opens a direct communication between the large cylinder and the reservoir, and the water returns to the reservoir.

221. The hydraulic press possesses this grand advantage, that *very little force is lost by friction.* It is one of the most economical as well as powerful means we have of producing great pressure, and is extensively used for pressing books, cotton, etc.; for testing the strength of ropes, chains, etc.; and two presses were recently employed to raise, through a height of more than one hundred feet, the great iron bridge, weighing more than 1800 tons, over the Menai Straits.

Example 1. In one of the Bramah presses used in raising the Britannia tube over the Menai Straits, the diameter of the piston, P, was 1 inch; that of the cylinder, P′, 20 inches; and the force applied to P at each stroke was 2½ tons. Calculate the lifting force produced by the upward motion of P′. *Ans.* 1000 tons.

Example 2. If the area of P be 20 square inches, and if it be pressed by a force of 360 pounds, calculate the diameter of P′, so that it shall be pressed upward by a force 10 tons.

Ans. Diameter of P′=39.8 inches.

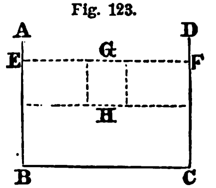
It may be observed that we have taken no account of the weight of the water in the cylinders; in practice, the weight of the water is neglected, because it is inconsiderable when compared with the enormous pressure which is commonly produced on the piston P′.

222. *Pressure due to the weight of liquids.*

If a solid body, as *a piece of ice*, of a cylindrical form, be placed in a vessel of the same size, the body will exert all its force upon the bottom, and there will be *no pressure against the sides*; but if

the ice be reduced to the liquid state, the pressure on the bottom will be the same as before, and pressure will also be exerted against each of the sides of the vessel. Let ABCD be a vessel filled with water up to the level EF. Let H be a horizontal stratum situated at any point within the liquid, and equal in extent to one square inch. The surface H will sustain the pressure of the column of liquid, GH, immediately above it; that is, every square inch of any stratum of the liquid must sustain a downward pressure equal to the weight of a column of the liquid whose base is a square inch, and whose height is equal to the depth of the stratum below the surface. But since this downward pressure is transmitted equally in all directions, it will act laterally with the same force as downward; that is, *each square inch of the surface of a vessel containing a liquid, is pressed by a force perpendicular to the surface, equal to the weight of a column of the liquid whose base is a square inch, and whose height is equal to the depth of the given surface below the top of the liquid.*

Fig. 123.

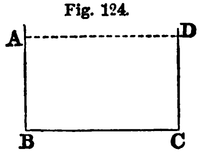


This proposition is equally true, whether the sides of the vessel be upright or inclined, either outward or inward.

223. *Pressure against the sides of vessels.*

The pressure against the sides of a vessel varies with the depth. Let ABCD be a vessel with vertical sides, filled with water. The pressure against the side AB, at the depth of one inch, being called 1, the pressure at the depth of two inches will be 2, at three inches 3, and so on. Since the pressure from A to B increases uniformly with the depth, the average pressure will be found at the middle point of the depth, and the total pressure upon the sides will be the same as if it sustained this average pressure uniformly distributed over the whole surface. Hence *the total pressure upon the side of the vessel will be equal to the weight of a column of the liquid whose base is equal to the area of the side, and whose height is one half the depth of the liquid in the vessel.*

Fig. 124.



If the vessel have a cubical form, the pressure on the bottom

will be equal to the weight of the liquid, and the pressure on each of the four sides will be equal to half the weight of the liquid; that is, *the total pressure on the bottom and sides will be three times the weight of the liquid in the vessel.*

224. The weight of a cubic foot of water is $62\frac{1}{2}$ pounds. Hence the pressure on every square foot of surface produced by water at the depth of 1 foot is $62\frac{1}{2}$ pounds,

2 feet is 125 "

8 " 500 "

16 " 1000 " and in the same ratio for greater depths. The pressure produced by water at great depths is enormous, as is indicated by various phenomena. If an empty bottle, tightly corked, be sunk to a sufficient depth in the sea, the pressure of the surrounding water will either break the bottle or force the cork into it.

Example 1. If each edge of a cubical reservoir filled with water be 10 feet, calculate the pressure on each of the sides, and also on the bottom.

Ans. Pressure on each side, 13.95 tons;
pressure on the bottom, 27.9 tons.

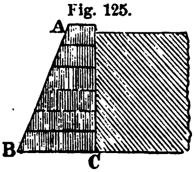
Example 2. The centre of a circular board, whose radius is 2 feet, is immersed to a depth of 10 feet; calculate the pressure upon it. *Ans.* Pressure=3.5 tons.

Example 3. A dyke to shut out the sea is 200 yards long, and is built in courses of masonry of one foot high; the water rises against it to a height of 36 feet. Calculate the pressures against the 1st, 18th, and 36th courses.

Ans. Pressure against 1st course=594 tons.
" 18th " =310 "
" 36th " = 8 "

The preceding example indicates the proper form to be given to a dam or embankment confining a reservoir of water. The pressure near the surface is small, but increases with the depth. The strength of the embankment should therefore increase from the top to the bottom, as shown in the figure ABC.

Fig. 125.



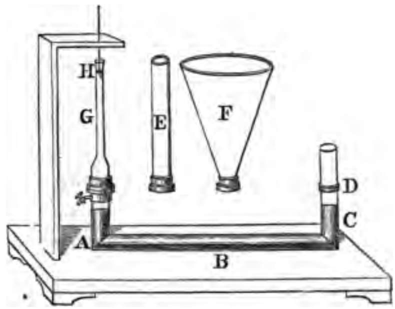
225. *Pressure independent of the form of the vessel.*

The pressure on the bottom of a vessel depends on the depth of the

liquid, and not on the form of the vessel or the quantity of liquid contained in it. This is proved by the following experiment.

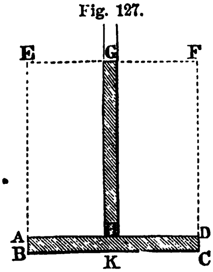
A bent tube, ABC, open at both ends, is partly filled with mercury, and a sliding index, D, shows the height to which the mercury rises in one arm. To the other arm of the tube, several vessels of different forms may be successively attached. We first attach a cylindrical vessel, E, and fill it with water to a definite height, H, and we mark the point to which the mercury rises in the other arm. The rise of the mercury in one arm of the tube measures the pressure exerted by the water on the other arm. We now draw off the water, and in place of the cylindrical vessel substitute another vessel, F, which expands at the top so as to contain a much larger amount of water. If we fill this vessel with water to the same height as before, the mercury in the tube will rise to exactly its former mark. Hence the pressure on the bottom of the vessel depends only on the size of the bottom, and the height of the water.

Fig. 126.



226. This principle leads to a very curious application. Let ABCD be a close vessel, with a small hole on the top, in which a narrow tube, GH, is inserted. Let the vessel and the tube be filled with water. The pressure on the bottom, BC, will be equal to the weight of a column of water whose base is equal to the area of the bottom, BC, and whose height is GK; that is, it is equal to the weight of a quantity of water which would fill a vessel whose base is BC, which has vertical sides, BE and CF, and whose height is BE.

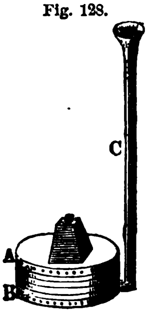
Fig. 127.



227. Thus *a very small quantity of water may be made to produce a pressure on the bottom of the vessel equal to the weight of any quantity of water, however great.* It is not necessary that the tube,

GH, should be straight; it may be bent, or have any form whatever. This principle is exemplified in *the hydrostatic bellows.*

Fig. 128.



This instrument consists of two circular boards, A, B, united by stout leather, like a common bellows, and a small vertical tube, C, communicates with the interior. If the bellows be loaded with heavy weights, and water be poured into the small tube, then, as the bellows is filled, the weights will be lifted. If the diameter of the bellows be 2 feet, and the height of the tube be 3 feet, the weight capable of being supported on the bellows is nearly 600 pounds.

228. In laying pipes for the supply of water to cities, those pipes which are much below the level of the reservoir should have a proportional strength, for they must sustain a pressure of 1000 pounds per square foot for every 16 feet by which they are depressed below the level of the reservoir. A pipe whose diameter is 4 inches has an internal surface of more than one square foot for every foot of length. If such a pipe were laid 80 feet below the level of the reservoir, it would sustain a pressure of 5000 pounds on each foot of its length.

If, through a fissure in a rock, there is a communication with an internal cavity situated at a considerable depth in the rock, and if water should enter so as to fill the fissure, it might exert a pressure sufficient to burst open the rock.

229. *Principle of Barker's Mill.* When the water contained in a vessel is at rest, the pressure on each side is counteracted by an equal pressure on the opposite side; but if we make an opening in one side of the vessel from which the water may escape, the pressure will be removed from this spot, while the pressure on the opposite side remains. The whole vessel, therefore, will tend to move in a direction contrary to that in which the water flows. This principle is applied in *Barker's mill.* A vessel, AB, is mounted so as to be capable of turning freely round a vertical axis, while to the bottom of the vessel are attached two horizontal tubes, C, D, whose extremities are bent at right angles to the tubes. When the vessel is filled with water, the water escapes through the open ends of the horizontal tubes; while the pressure of the water in one direction, not being bal-

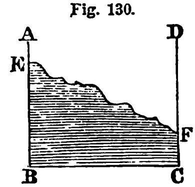
Fig. 129.

anced by an equal pressure in the contrary direction, gives the vessel a rapid rotary motion. The ends of the arms are so bent that the pressure on each arm tends to turn the vessel in the same direction. This motion will continue as long as the supply of water is maintained.

230. *Surface of a liquid at rest.*

When the liquid contained in a vessel is in a state of rest, *its surface must be horizontal,* for otherwise the liquid can not rest. Let ABCD be a vessel containing a liquid whose surface, EF, is *not horizontal.* The column EB will exert a pressure equal to its weight, and this pressure will be transmitted equally in every direction. The column FC will also exert a pressure equal to its weight, and this pressure will be transmitted equally in every direction. But if the column EB be the highest, it will exert the greatest pressure, and theretore the liquid will move in the direction from B to C, and it will not rest until the column EB has the same height as FC; that is, until the surface EF is horizontal.

Fig. 130.



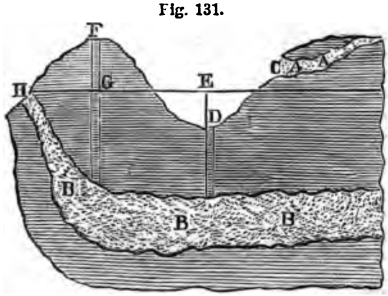
231. *Liquids in a system of communicating vessels.*

For the same reason, if the liquid be contained in different vessels, which have free communication with each other by tubes or otherwise, the surfaces of the liquids in the different vessels will be at the same level. So, also, *the water must stand at the same level in the opposite arms of a bent tube,* whether the arms be of equal or unequal diameter, and whatever be their shape or position.

This principle enables us to explain many phenomena of *springs and Artesian wells.* The water which falls from the clouds penetrates the soil, and sometimes reaches to a great depth. It

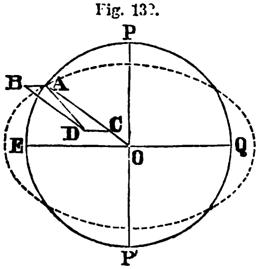
sometimes encounters strata which are impervious to water, and is thereby walled in, in a subterranean reservoir. The water thus accumulated is subject to the laws of hydrostatic pressure, which gives rise to springs and wells. The annexed figure is designed to represent a vertical section of the earth: AA and BBB represent porous strata filled with water, and surrounded by other strata which are impervious to water. The water from AA will issue from C as from a spring, with a force proportional to the height of the column AA. If a vertical shaft be sunk at D until it reaches the stratum B, the water will rise to a height E, equal to the level of the highest point of the reservoir H, and will form a jet, or Artesian well. If a shaft be sunk at F until it penetrates the stratum B, the water will ascend in it to the level G, and will form a well; but the water will not rise to the surface without the assistance of a pump. A few years since a boring was made at Paris to the depth of 1837 feet, and the water now rises from it in a permanent stream 30 feet above the surface of the ground.

Fig. 131.



232. *A level surface.* If the earth were at rest, and entirely covered with a liquid, and no forces acted upon its particles except their mutual attraction, it would assume a spherical form; but it has been ascertained by measurement that the earth's surface is that of an oblate spheroid, the polar diameter being to the equatorial as 299 to 300. This deviation from the spherical form is a consequence of its rotation upon its axis. Let PEP′Q be a section of a sphere passing through its axis of rotation, PP′, and let A be any point on its surface. When the sphere turns upon its axis, this point will describe a circle parallel to the equator, and there will result a centrifugal force acting in the direction AB, perpendic-

Fig. 132.

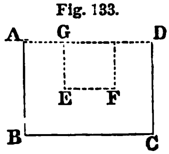


ular to PP′. Let AC represent the attraction of the earth, and AB the centrifugal force. The resultant of these two forces will be represented by the diagonal AD. Now *if the surface of a liquid be entirely free, it must at every point be perpendicular to the resultant of the forces which act upon that point.* Hence the surface (which was at first supposed spherical) must change its form, so that at each point the surface may be perpendicular to the direction of the total forces acting at that point. The form assumed will be such as is represented in the figure by the dotted line, and may be proved to be a spheroid, formed by the revolution of an ellipse about its minor axis. *This spheroidal surface is called a level surface.*

233. *The pressure around any point in a liquid at rest is equal in every direction.* This follows from the definition of a liquid, being a body whose particles yield to the slightest force. If the pressure upon a particle in one direction were greater than that in any other direction, the particle must move. This principle applies not merely to external pressure, but also to the pressure which arises from the weight of the liquid.

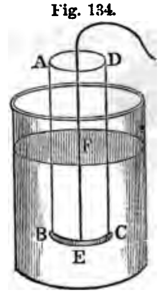
If we suppose EF to represent a horizontal stratum in the interior of a mass of water, each square inch of this stratum sustains a column of water whose height is EG. But since fluids press equally in all directions, the upward pressure at E must be equal to the downward pressure; that is, the upward pressure at E is equal to the weight of a column of water whose height is EG. This conclusion is verified by the following experiment.

Fig. 133.



Take a large glass tube, ABCD, whose bottom is ground to an even surface; also a brass disk, E, secured at its centre by a cord, F, passing through the tube, so that by drawing the cord the disk may be made to close the opening of the tube. When the tube is thus immersed in water to a certain depth, it is no longer necessary to draw the cord to prevent the disk from falling off, for it is held against the tube by the upward pressure of the water; but if we elevate the tube, we shall find a certain point where the disk falls off, and this happens

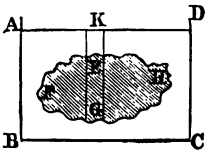
Fig. 134.



when the upward pressure of the water is just equal to the weight of the disk.

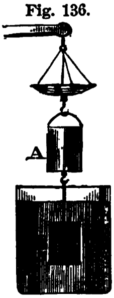
234. *Principle of Archimedes.* It follows from the preceding Article, that *a solid immersed in a liquid loses an amount of weight equal to that of the liquid it displaces.* Let ABCD be a vessel containing a liquid, and let EFGH be a solid immersed in the liquid. Consider any vertical section of the solid as EG. The point E will be pressed downward by a force equal to the weight of the column of water KE, and the point G will be pressed upward by a force equal to the weight of the column GK. Hence the upward pressure exceeds the downward pressure by the weight of a column of water equal to EG, and a similar remark applies to every other portion of the solid. Hence *the upward pressure exceeds the downward pressure by a force equal to the weight of the liquid displaced.*

Fig. 135.



This conclusion is verified by the following experiment. To one of the arms of a balance is attached a hollow cylinder, A, from which is suspended a solid cylinder, B, of such dimensions as exactly to fill the cavity of the former. From the other arm of the balance is suspended a weight to counterpoise the whole. If now the solid cylinder be immersed in water, it will lose a portion of its weight, and the equilibrium will be destroyed; but if we fill the hollow cylinder with water, the equilibrium will be restored as at first, showing that the loss of weight of the cylinder in consequence of being immersed in water, is the weight of an equal volume of water. This principle was discovered by Archimedes more than 200 years before Christ.

Fig. 136.



SECTION III.

EQUILIBRIUM OF FLOATING BODIES.

235. *When a solid floats on a liquid, it displaces as much of the liquid as is equal to its own weight;* for the upward pressure is equal to the weight of the fluid which it displaces, and the downward pressure is equal to its own weight; and if the body floats, these two pressures must be equal to each other. Solids, therefore, can never float, if they are heavier than an equal bulk of the liquid in which they are immersed.

A block of stone is much more easily lifted at the bottom of the sea than it would be on land; being lighter by an equal bulk of sea water.

The weight of the human body does not differ much from that of an equal bulk of water. When the lungs are filled with air, the body is lighter than water; but when the air is expelled, the body is heavier than water. When an animal is first drowned, the air being expelled from the lungs, the body is heavier than the water, and sinks; but when decomposition takes place, gases are generated, the body becomes lighter than water, and rises.

236. *If a solid be immersed in a liquid, it will displace as much of the liquid as is equal in volume to the part immersed,* and thus the magnitude of a solid of irregular shape may be determined by plunging it in a vessel brimful of water, and observing how much of the water is made to overflow.

The weight of a ship, including its cargo, can be determined by measuring the volume of the water it displaces.

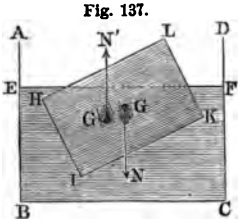
237. *Stability of floating bodies.*

When a solid floats upon a liquid, the upward pressure of the liquid is equal to the weight of the fluid displaced, and may be regarded as a simple force whose direction passes vertically through the centre of gravity of the fluid displaced. This point is called *the centre of buoyancy.* But the downward pressure due to the weight of the body, is a force which passes through the centre of gravity of the body itself. If these two centres of buoyancy and gravity are not in the same vertical line, the body

will tend to turn round in the liquid until both points are brought into the same vertical line.

Let ABCD be a vessel containing a liquid whose surface is EF, and let HK be a body floating upon it. Let G be the centre of gravity of the body, and G′ its centre of buoyancy; that is, the centre of gravity of the liquid displaced. The downward pressure due to the weight of the body, takes place in the vertical line GN, while the upward pressure exerted by the liquid takes place in the vertical line G′N′. The body, HK, is therefore acted upon by two equal forces, which tend to turn the body round in the direction HLKI; and this motion will continue until G and G′ are brought into the same vertical line. That is,

Fig. 137.



238. *A solid floating upon a liquid will not rest, unless the line joining the centre of gravity and the centre of buoyancy is vertical.* When this line is vertical, the resulting equilibrium may be either *stable*, *unstable*, or *neutral*.

When the centre of gravity is vertically *over* the centre of buoyancy, *the equilibrium will be unstable*, and the slightest external force will overturn it.

When the centre of gravity is vertically *under* the centre of buoyancy, *the equilibrium will be stable;* and if the body be made to deviate a little from this position, after a few oscillations it will return again to the same position.

If the form of the body be such that the centres of gravity and buoyancy are necessarily *in the same vertical line*, whatever may be the position of the body, the body will rest in any position, and this constitutes *a neutral equilibrium.* This is the case with a sphere of uniform density.

The stability of a floating body increases with the distance of its centre of gravity below its centre of buoyancy. For this reason, vessels which carry light cargoes require to be ballasted by depositing near the keel a quantity of heavy materials. Iron and stone are frequently carried for this purpose.

239. Fishes have the same specific gravity as the water in which they float, and rest indifferently at the top or bottom of a lake. In order to preserve them upright in the water, they have

air-vessels situated in the upper part of the body, so that the centre of gravity is below the centre of magnitude. They have also the power of compressing these air-vessels, and thus condensing the contained air when they wish to descend, and of allowing the air to expand again when they wish to rise to the surface of the water. This process is illustrated by an apparatus represented in *Fig.* 138. This apparatus consists of a small hollow glass figure, with a capillary opening, through which enough water is admitted to make the specific gravity of the figure a little less than that of water. The upper part of the figure contains air. The figure is placed in a glass vessel filled with water, and over the mouth of the vessel is tied a sheet of India-rubber. By pressing the finger upon the India-rubber, the air in the small figure is compressed, more water is forced into it, its specific gravity is thereby increased, and it sinks to the bottom. On removing the finger, the air in the figure expands, the excess of water is driven out, and the figure, becoming lighter than water, rises to the surface.

Fig. 138.

SECTION IV.

SPECIFIC GRAVITY AND HYDROMETERS.

240. *The specific gravity of a body is its weight compared with that of an equal bulk of another body taken as a standard.*

For all solid or liquid bodies, *water is taken as the standard.*

When we say that the specific gravity of brass is 8, we mean that a cubic inch of brass weighs 8 times as much as a cubic inch of water. Since the weight of a cubic inch of water varies with its temperature, the temperature at which the water is employed should always be mentioned. The temperature at which water is now generally taken as the standard, is that of 39° Fahrenheit, which corresponds to the maximum density of water.

To determine the specific gravity of a solid which is heavier than water, we weigh it first in air, and then in water. The difference between these two weights is the weight of a quantity

of water equal in volume to the solid. Then *divide the weight in air by the loss of weight in water, the quotient will express the specific gravity of the body.*

Example. If a piece of marble weighs $1967\frac{1}{2}$ grains in air, and 1240 grains in water, what is its specific gravity?

Ans. $\frac{1967.5}{727.5}=2.704.$

241. The specific gravity of a solid which is *soluble in water* may be determined by immersing it in some other liquid in which it is not soluble, and determining its specific gravity with reference to that liquid. Then, having determined the specific gravity of this liquid with reference to water, we can compute the specific gravity of the solid with reference to water.

To determine the specific gravity of a solid which is *lighter than water*, we weigh it first in air; then, to determine the weight of an equal bulk of water, attach to it another solid such that the two, when connected, may sink in water. Determine the weight which they both lose by immersion; then determine the weight which the heavier solid alone loses by immersion. The difference will be the weight of an amount of water equal in volume to the lighter solid. The weight in air divided by this difference, will express the specific gravity.

Example. A specimen of granite weighed in air 972 grains, and in water $622\frac{1}{2}$ grains. A small piece of cork weighed in air $125\frac{1}{2}$ grains, and when attached to the granite, both together weighed 176 grains in water. Required the specific gravity of the granite, and also of the cork.

Ans. Sp. gr. of the granite$=\frac{972}{349\frac{1}{2}}=2.78$;

sp. gr. of the cork$=\frac{125\frac{1}{2}}{572}=0.22.$

242. To determine the specific gravity of a liquid, *weigh equal volumes of the liquid and of water, and divide the former result by the latter;* or weigh a solid body both in the liquid and in water, and divide the loss of weight sustained by the solid in the liquid, by the loss of weight it sustains in water.

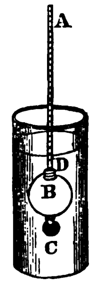
Example. If the weight of a given quantity of water is 1400 grains, and the weight of the same quantity of alcohol is 1164 grains, what is the specific gravity of the alcohol? *Ans.* 0.793.

Two columns of liquids in a recurved tube balance each other when their heights are inversely as their specific gravities. We find that a column of mercury one inch in height will balance a column of water 13½ inches in height; hence the specific gravity of mercury is 13½.

243. HYDROMETERS.

The hydrometer is an instrument for determining the specific gravity of bodies. The common hydrometer consists of a hollow ball, B, with a long, slender graduated stem, AD; and the ball is so loaded by a weight, C, that the stem will stand upright in water. The lighter the fluid, the greater the depth to which the hydrometer will sink. The scale should be so graduated that when the hydrometer is immersed in pure water at the standard temperature, it may sink to the point which is marked 1.00.

Fig. 133.



Some hydrometers have a long scale, and show the specific gravity of liquids for a wide range, both above and below unity; but most hydrometers are made for a specific purpose, and have but a limited range. Thus an hydrometer designed to test the purity of milk need extend only from 1 to 1.03.

To determine the specific gravity of a liquid by means of the common hydrometer, we immerse the hydrometer in the liquid, and observe what division on the scale of the instrument corresponds to the surface of the liquid. This number will indicate the specific gravity of the liquid.

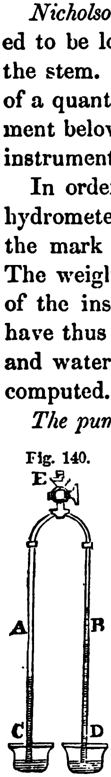
244. *Cartier's hydrometer* is an instrument long employed by the French government for testing the quality of distilled spirits. This instrument is graduated in the following manner. It is first immersed in water containing 10 per cent. of common salt, and the point to which it sinks is marked 0. It is then immersed in pure water, and the point to which it sinks is marked 10. The interval is graduated into equal parts, and the scale is extended upward by repeating the same interval upon the stem. This instrument, therefore, merely furnishes degrees of the hydrometer, and not specific gravities; but tables have been constructed by which its indications may be converted into specific gravities.

0	degrees on Cartier's hydrometer		=1.073	specific gravity.
10	"	"	=1.000	"
20	"	"	= .936	"
30	"	"	= .879	"
40	"	"	= .829	"

Nicholson's hydrometer is provided with a dish, which is designed to be loaded until the instrument sinks to a fixed mark on the stem. It is designed to be so constructed that the weight of a quantity of water equal in volume to the part of the instrument below the fixed mark, shall be equal to the weight of the instrument together with 1000 grains.

In order to determine the specific gravity of a liquid, let the hydrometer be immersed in it, and let the dish be loaded until the mark on the stem is brought to the surface of the liquid. The weight of the liquid displaced will be equal to the weight of the instrument, together with the weight in the dish. We have thus ascertained the weight of equal volumes of the liquid and water, from which the specific gravity of the liquid may be computed.

Fig. 140.



The pump hydrometer consists of two long vertical tubes, A, B, open at the bottom, and inserted in separate cups, C and D, one of which contains water, and the other contains any liquid whose specific gravity is to be determined. The two tubes are united at the top, and the air within them may be rarefied by means of an exhausting syringe. Since the pressure of the air must be the same in both tubes, the heights to which the liquids rise afford a measure of their specific gravities.

245. The specific gravity of a body often affords the means of detecting important qualities. Thus distilled spirits are a mixture of pure alcohol with other bodies, chiefly water. The value of the liquid depends upon the proportion of pure alcohol which it contains, and this is indicated by its specific gravity.

In like manner, gold, when used in the arts, is generally alloyed with baser metals, the presence of which is indicated by the specific gravity of the alloy. The following table shows the specific gravity of some of the more common substances.

Iridium	23.00	Silver	10.47	Brick	2.00
Platinum	22.06	Copper	8.90	Water	1.00
Gold	19.31	Brass	8.30	Ice	.92
Mercury	13.60	Iron	7.78	Alcohol	.79
Lead	11.35	Marble	2.71	Cork	.24

246. Since a cubic foot of water weighs 1000 ounces, a cubic foot of gold must weigh more than 19 times as much, or 19,310 ounces; a cubic foot of marble must weigh 2710 ounces, etc.; that is, when we know the volume of a body as well as its specific gravity, we can compute its weight. This method is employed for determining the weight of large masses of rock, or other substances, of such dimensions as could not be lifted by steelyards.

Example 1. What is the weight of a cube of gold whose edge is 3 inches? *Ans.* 18.845 pounds.

Example 2. An iceberg is 60 fathoms high, 50 fathoms wide, and 40 thick. Calculate its weight in tons.

Ans. 662,120 tons.

Example 3. What is the weight of 10,000 bricks whose dimensions are 8 inches by $3\frac{1}{2}$ by $2\frac{1}{2}$? *Ans.* $22\frac{1}{2}$ tons.

247. The gold of California is generally found firmly imbedded in a mineral called quartz. A piece of quartz containing gold is called a nugget. The weight of gold in a nugget may be computed, when we know the weight of the united mass, together with its specific gravity.

Let G be the weight of the gold, and g its specific gravity.
" Q " quartz, " q "
" N " nugget, " n "

Then, since the volume of a substance is equal to its weight divided by its specific gravity, we have

$$\frac{G}{g}+\frac{Q}{q}=\frac{N}{n},$$

and also $$G+Q=N.$$

From these equations, we obtain

$$G=N\frac{g(n-q)}{n(g-q)}.$$

Example 1. The specific gravity of a nugget whose weight is $11\frac{1}{2}$ ounces, is 7.43; how much fine gold does it contain, the specific gravity of the quartz being 2.62? *Ans.* 8.61 ounces.

Example 2. A nugget weighs 32 ounces; its specific gravity is found to be 4.13; how much gold does it contain, the specific gravity of the quartz being 2.71? *Ans.* 12.79 ounces.

SECTION V.

CAPILLARY ATTRACTION.

248. Under capillary attraction is classed a variety of phenomena belonging to molecular action, among which the ascent of liquids in capillary tubes is the most conspicuous. A tube whose bore is less than one tenth of an inch, is called *a capillary tube*, from capillus, a hair.

249. *Adhesion of solid bodies.* If the surfaces of two solid bodies are rendered perfectly smooth, and then brought into close contact by strong pressure, they will adhere with considerable force. This adhesion may be exhibited by two disks of smooth ground glass. This adhesion is not due to atmospheric pressure, for it continues in a vacuum; but the molecules of the two bodies are brought into so close contact as to be within the sphere of each other's attraction.

By interposing some substance in a liquid form which hardens by cold, the adhesion of the surfaces of solids may be rendered greater than the cohesion of the particles of the solids themselves. Two pieces of wood well glued together will break any where sooner than at their joint.

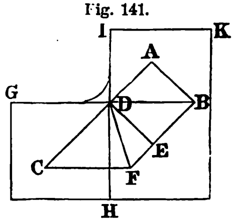
250. *Adhesion of liquids to solids.* There is also an adhesion between the surfaces of many solid and liquid bodies. Thus mercury adheres to copper, silver, gold, etc. Water adheres to glass, wood, paper, etc. *We may measure the force of this adhesion* of two surfaces, by placing them in a horizontal position, the lower one being attached to a fixed object, and the upper one being connected with the arm of a balance, and observing the weight necessary to separate them. The attraction of the surface of water for a circular glass disk four inches in diameter, is equal to 625 grains, or 50 grains for one square inch of surface, showing that *each square inch of surface lifts about one fifth of a cubic inch of water.*

The attraction of mercury for glass is equal to 175 grains for each square inch of surface.

Adhesion does not invariably exist between solids and liquids. If we plunge the hand into a basin of water, on withdrawing it, a quantity of water adheres to the skin. If we dip the hand into a basin of mercury, the liquid will not adhere. If a body coated with oil be immersed in water, it will not be wet. Mercury adheres to gold, lead, etc., but it will not adhere to iron or platinum.

251. *If a liquid be contained in a glass vessel whose sides are vertical, and if the attraction of the glass for the liquid be more than half that of the particles of the liquid for each other, the liquid near the glass will be elevated, and its surface will be concave.*

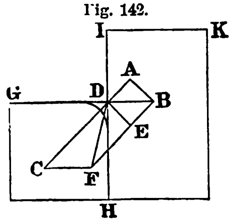
Fig. 141.



Let HK represent a portion of a glass vessel, and GH the liquid in contact with it. The particles of the liquid situated at D may be considered as acted upon by three forces, one due to the attraction of the liquid, which may be represented by the line CD, bisecting the angle GDH; the other two forces are due to the attraction of the two portions of the glass above and below the surface of the liquid, which may be represented by the lines DA and DE, bisecting the angles IDB and BDH. The resultant of DA and DE is DB; and the resultant of DB and DC is DF, which is inclined toward the glass when DA is more than half of DC. Consequently, since the surface of a liquid at rest must be perpendicular to the resultant of all the forces acting on it, the surface of the liquid must be more elevated at the side of the vessel than elsewhere, and therefore *concave.*

If the attraction of the glass for the liquid be less than half that of the particles of the liquid for each other, the liquid will be depressed, and its surface will be convex.

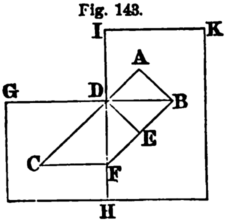
Fig. 142.



If AD be less than half of CD, the resultant, DF, will be inclined toward the liquid, and the surface of the liquid, in order to be perpendicular to it, must be depressed near the side of the vessel, and therefore *convex.*

If the attraction of the glass for the liq-

Fig. 143.

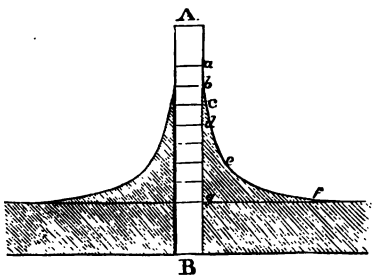


uid be exactly half that of the particles of the liquid for each other, the surface of the liquid will be horizontal.

If water or alcohol be contained in a glass vessel, the surface of the liquid near the glass will be elevated; hence the attraction of glass for these liquids is *more than half* as great as the attraction of the particles of these liquids for each other. But if mercury be contained in a glass vessel, the surface of the mercury near the glass will be depressed; hence the attraction of glass for mercury is *less than half* as great as the attraction of the particles of mercury for each other.

252. *If a plate of glass,* AB, *be plunged vertically into a vessel of water, the water will rise upon the glass and cover it to the height of about one sixth of an inch.* The quantity of water thus supported by one side of a plate, is about the $\frac{1}{100}$ part of a cubic inch of water for each linear inch along the glass parallel to the horizon, and the outline of the water forms a curve, $b\,e\,f$. This result is *entirely independent of the thickness of the glass,* from which we infer that the attraction of the glass for water does not extend to any sensible distance. The attraction of the glass does not extend to so great a distance as $b\,f$, or even as the perpendicular height $b\,g$ of the curve. It is only a very small portion of glass, $a\,b$, that is effectual in supporting the water; for the action of every other portion of the glass tends as much to depress as to elevate the water. Thus the portion $c\,d$ of the glass, while it attracts the water below it upward, also attracts the water above it downward. These two actions exactly neutralize each other; and the same is true of every part of the glass except the narrow band, $a\,b$, immediately above the surface of the water. The nearest particles of water appear to be supported by the attraction of the glass, $a\,b$; the

Fig. 144.

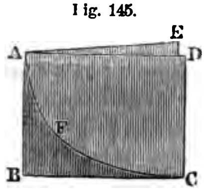


next particles cohere to the first; these also support other particles, and so on, until the weight of the accumulated water becomes equal to the cohesion of the particles of water near $a\ b$.

253. If *two plates of glass* be fixed parallel to each other, with a small interval between them, the weight of water supported will be *double what it was with a single plate.* If the plates be brought nearer together, the water will rise between them, so that the weight supported may still be the same. Hence *the height of the water will be inversely as the distance of the plates.*

If the interval between the plates be the $\frac{1}{100}$ of an inch, then, since each linear inch of each plate will support the one hundredth part of a cubic inch of water, the water will stand at the height of $\frac{200}{100}$, or 2 inches.

Fig. 145.



If two glass plates, BD, BE, be brought into contact at their vertical edges on one side, AB, but be kept open at the other, the water at different points will rise to heights inversely as the distance of the plates at those points, and *its outline,* AFC, *will form an hyperbola.*

254. If four narrow plates be joined at their edges so as to form a square prism, and be immersed in water, the water, being supported on four sides instead of two, *will rise to twice its former height.* Also, because the circumference of a circle is to its area as the perimeter of the circumscribed square is to its area, the water will stand at the same altitude in a cylindrical tube as in the circumscribing prism.

A tube $\frac{1}{100}$ inch in diameter therefore raises water 4 *inches;* and since the height in different tubes varies inversely as the diameter, a tube $\frac{1}{10}$ inch in diameter will raise water 0.4 inch. The top of the column of water in a capillary glass tube is always *concave.*

Different liquids rise to unequal heights in the same tube. In a tube $\frac{1}{100}$ inch in diameter,

water rises		4 inches.		
nitric acid	"	3	"	
alcohol	"	1.6	"	
whale oil	"	1.5	"	

255. *Action of glass on mercury. If a plate of glass be plunged vertically into a vessel of mercury, the mercury near the surface of*

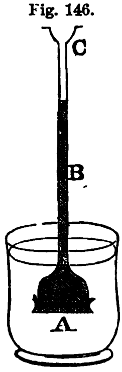
the glass will be depressed. If two parallel plates be employed, the depression will be double of that produced by one plate; and, since the depressing force is the same whether the distance between the plates be great or small, this force will always be balanced by a given weight of mercury; that is, *the depression must be inversely as the distance of the plates,* and it must be twice as great in a tube whose diameter is equal to the distance of the plates.

It is found by experiment that in a glass tube $\frac{1}{68}$ inch in diameter, the depression is one inch; hence the depression in any other glass tube whose diameter is D will be nearly $\frac{1}{68D}$. In a tube whose diameter is $\frac{1}{10}$ inch, the depression is $\frac{1}{7}$ inch; and in a tube whose diameter is $\frac{1}{4}$ inch, the depression is $\frac{1}{17}$ inch. *The top of the column of mercury in a capillary glass tube is always convex.*

These phenomena are explained by the fact that, although the glass has an attraction for the mercury, this attraction is less than half the attraction of the particles of mercury for each other, which causes a depression of the surface of the mercury, as shown in *Art.* 251.

256. It is by the force of capillary attraction that oil rises through the pores of the wick to feed the flame of a lamp. If one end of a lock of candle-wick be immersed in a basin of water, the other end hanging over its edge, the water will ascend through the pores of the cotton until the basin is emptied. Mercury will rise in the same manner through the pores of a solid cylinder of lead.

Fig. 146.



If at the bottom of a mass of sand or sugar, moisture be supplied, it will ascend through the pores in opposition to gravity, and the entire mass of sand or sugar will become damp.

257. *Endosmose.* If we take a glass tube, BC, expanding at one end, A, in the form of a funnel, and, having tied a piece of bladder over the open end, A, fill the vessel with alcohol to a certain point, and then immerse it in a vessel of water to the same level, we shall find the liquid slowly rise in the tube to a point much above its former height. *The alcohol attracts the water,* but the bladder is in-

terposed to separate them. *The bladder attracts the water, while it repels the alcohol.* A portion of water, being first attracted by the bladder, and then by the alcohol, makes its way through the pores of the bladder, and is immediately mixed with the alcohol, in which condition it is no longer attracted by the bladder. A fresh portion of water passes through the bladder, and this process continues until the alcohol is considerably diluted. While the water thus flows toward the interior of the tube, a little of the alcohol moves in the opposite direction. This current from without inward is called *endosmose* (ενδον and ωσμος), signifying a pushing inward; the current from within outward is called *exosmose* (εξ and ωσμος).

In consequence of this action, if a bladder be filled full of alcohol, and its neck be firmly secured, it will soon burst if it be plunged beneath water.

SECTION VI.

LAWS OF THE MOTION OF LIQUIDS.

258. If a small hole be made in the side of a vessel containing a liquid, the liquid will issue with a velocity depending upon the pressure. This pressure is the weight of a column of the liquid whose height is the depth of the hole below the surface of the liquid; and *the velocity with which the liquid issues is the same which a heavy body would acquire in falling from the surface of the liquid to the aperture.*

Hence *the velocity of escape depends not on the nature of the liquid,* but on the depth of the aperture below the surface. With equal heights of pressure, mercury and water escape with equal velocities.

If the liquid escape by a jet directed vertically upward, it will rise to the level of the liquid in the reservoir; for if a heavy body be projected upward, it will rise to the height from which it must have fallen to acquire the velocity of projection.

This proposition supposes that there is no resistance from the air, and no friction against the sides of the aperture.

259. *The velocity with which the liquid escapes, varies as the square*

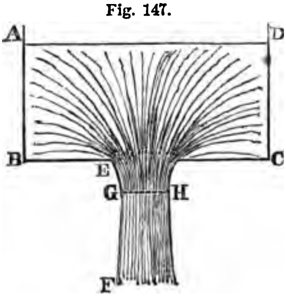
root of the depth below the surface. For, let H represent the depth of the orifice below the surface, then, by *Art.* 169, the velocity acquired in falling through H, is $2\sqrt{Hg}$, which varies as the square root of H. Hence if, in a vessel containing a liquid, orifices be made at the depth of 1, 4, 9, 16, etc. feet, the velocities with which the liquid will escape will be as 1, 2, 3, 4, etc.

The quantity of water issuing from an aperture in a vessel in a given time, depends upon the size of the aperture and the velocity of escape. From the principles already stated, we should infer that the water escaping in one second from a circular aperture, would form a cylinder whose base is equal to the aperture, and its length equal to the distance described by a particle of water in one second, which distance should be the velocity acquired by a body in falling from the surface to the orifice. This is called *the theoretical discharge.*

260. It is found by experiment that *the quantity of water actually discharged is only about two thirds, or* 0.62, *what this theory would give.* This discrepancy is ascribed to *the convergence and consequent interference of the currents of water* as they move toward the aperture.

We may exhibit this convergence of the currents palpably to the eye, by mixing with the water some small particles of amber, which has nearly the same specific gravity as the water, and therefore remains suspended in it, and by its motions indicates the movement of the particles of the water. We find that for a considerable distance around the orifice, and from all directions, the particles move nearly in direct lines toward the orifice. In consequence of this convergence of the particles toward the orifice, the jet, EF, issuing from a circular aperture in the thin side of a vessel, ABCD, is not of a cylindrical form, but contracts its dimensions immediately on leaving the orifice, and at a distance equal to about half the diameter of the orifice, the diameter of the jet is only $\frac{8}{10}$ of the diameter of the orifice, or the section of the jet is about two thirds of the area of the orifice.

Fig. 147.



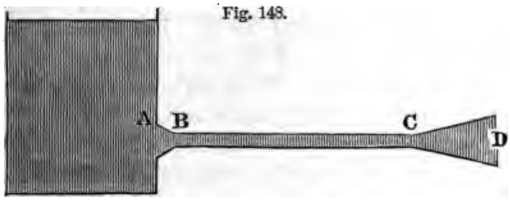
This point of greatest contraction, GH, *is called the vena contracta.* Beyond the vena contracta the section still diminishes, though much less rapidly than before. This is due to the fact that the velocity of the particles, according to the laws of falling bodies, increases as they descend, and a column of water, which at the aperture was one inch in length, is drawn out into a greater length as it descends, and therefore decreases in its diameter.

Since the same quantity of liquid must pass through any two sections of the stream in the same time, the velocity of the liquid at the vena contracta must be greater than that at the orifice; and *it is the velocity at the vena contracta which is found to be equal to that which a body would acquire in falling from a height equal to the depth of the orifice.*

261. If a cylindrical tube whose length is three times its diameter be attached to the orifice, the discharge of water will be greater than from a simple aperture, being $\frac{82}{100}$ instead of $\frac{62}{100}$ of that given by theory.

If we attach to the aperture a smoothly polished metallic mouth-piece, having the form of the vena contracta, the water discharged will be about $\frac{98}{100}$ of that given by theory. If we make the entrance to the pipe, AB, of the shape of the vena

Fig. 148.



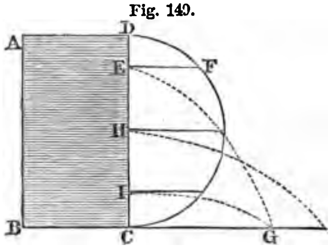
contracta, and the other extremity, CD, slightly divergent, like the mouth of a trumpet, the discharge will be still farther increased. When the divergence of the sides of the mouth is about five degrees, the quantity discharged is $2\frac{1}{2}$ times as much as through a simple orifice in a thin plate.

262. *A stream of water flowing from a vessel in any direction except vertically, describes a parabola;* for this is the case of a heavy body projected into the air, and acted upon at the same time by the force of gravity. The range is the greatest when the angle of elevation is 45°, and is the same for elevations equally above

and below 45°, as, for example, 20° and 70°. These conclusions are strictly true only in a vacuum.

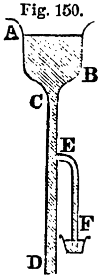
If a semicircle be described on the vertical side of a vessel, ABCD, as a diameter, and the vessel be filled with a liquid which escapes from any point, E, through a small orifice, the range CG will be equal to twice the length of the ordinate EF belonging to that point. Hence the range will be greatest when the liquid spouts from the centre, H, and will be equal for equal distances above and below the centre, as E and I.

Fig. 149.



263. Water at rest presses equally in all directions, but *water in motion does not press equally in all directions.* A stream of water descending vertically from a reservoir without resistance exerts *no lateral pressure,* but the air in contact with it is dragged along by friction, and the neighboring air rushes in to supply its place. This is shown in the following experiment.

Fig. 150.



Let AB be a reservoir of water, and CD a vertical tube at least half an inch in diameter, through which water may descend freely. Let a small opening be made in the side of the tube at E, and attach to it a small bent tube, EF, whose lower end is immersed in a vessel containing some colored liquid. When the water is flowing freely through CD, it exerts no pressure against E; and, as the column of water contracts in its descent, it does not entirely fill the tube at E, but is surrounded by a thin sheet of air. This air is dragged along by friction against the water, and the external air presses up the water from the vessel, F, to supply its place. If the tube, EF, be not too long, the liquid from F will enter the larger pipe, CD, and be discharged at D.

If a small tube be inserted in a similar manner near the vena contracta, we shall find that the pressure of the water from within, is less than that of the air from without.

264. *Resistance of liquids.* If a solid be moved through a liquid which is at rest, it will suffer a certain resistance depending

on its form and magnitude. This resistance arises from the reaction of the liquid which the solid displaces, and to which it imparts motion. Whatever force the liquid receives must be lost by the solid. With a given velocity, *the resistance is proportional to the magnitude of the surface;* for a surface which measures two square feet will displace a column of water twice as great as a surface measuring one square foot.

The resistance will also depend upon the velocity. If the surface be moved with a double velocity, the liquid which it drives before it will also be moved with a double velocity, and will have a double momentum; but when the surface is moved with a double velocity, it advances through a double space in the same time, and therefore displaces a double quantity of liquid. Now this double quantity of liquid, moving with a double velocity, must have a four-fold momentum; that is, when a flat surface of a given area is moved through a liquid, *the resistance increases as the square of the velocity.* Thus a double velocity gives a four-fold resistance; a treble velocity, a nine-fold resistance, and so on. Hence, in general,

The resistance encountered by a flat surface moving through a liquid, is proportional to the area of the surface multiplied by the square of the velocity.

It is found that a square foot of surface moved with the velocity of 32 feet per second, suffers a resistance equal to a weight of 1000 pounds. We can hence compute the resistance due to any other velocity or amount of surface.

If the surface be not perpendicular to the motion of the liquid, we must resolve the motion into two, one of which is perpendicular to the surface, and the other parallel to it. The latter component can have no effect in opposing the motion of the surface.

265. One of the most celebrated problems in the history of the mathematics, has been to determine the form which should be given to a solid body in order that it may move through a liquid with *the least possible resistance.* This form is called *the "solid of least resistance."*

The models of ships should be conformed to the proportions of the solid of least resistance, as far as is consistent with strength and other important qualities.

The forms of most varieties of fishes are adapted to swift mo-

tion through the water, and approach nearly to the form of the solid of least resistance.

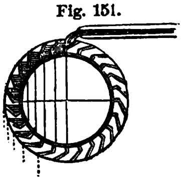
SECTION VII.

HYDRAULIC MACHINERY.

266. Moving water is applied to mechanical purposes chiefly through the medium of wheels. There are three varieties of water-wheels in common use, *the overshot*, *the undershot*, and *breast wheel.*

In *the overshot wheel*, the water is poured over the top, and thus acts principally, though not exclusively, by its weight. A stream of water falls into a bucket at the top of the wheel, and the water is retained until the bucket reaches the bottom of the wheel.

Fig. 151.



When the loaded bucket is directly over the axis of the wheel, it produces merely pressure upon the axis, and has no tendency to give the wheel a rotary motion; but as the wheel is turned, the weight of the water acts upon a lever, whose length is continually increasing until the wheel has made one quarter of a revolution, when the effect of the water is the greatest; and during the next quarter of a revolution, the effect continually decreases until the water is discharged at the bottom. *The total mechanical effect is measured by the quantity of water which descends in the buckets, multiplied by the height through which it falls.*

This wheel is used where the supply of water is scanty and the fall is considerable, as in small mountain streams.

Fig. 152.

In *the undershot wheel*, float-boards placed at right angles with the circumference of the wheel are employed, and the wheel is turned merely by the force of the current running under it and striking upon the boards. This wheel is used when the supply of water is abundant, but the fall is slight. Ex-

periments show that the most work is done in a given time, when the velocity of the wheel is about half that of the flowing water.

In *the breast wheel*, the water falls down upon the wheel at right angles to the float-boards or buckets. If float-boards are used, the water acts only by its impulse; but if buckets are used, it acts also by the weight of water in the buckets in the lower quadrant of the wheel.

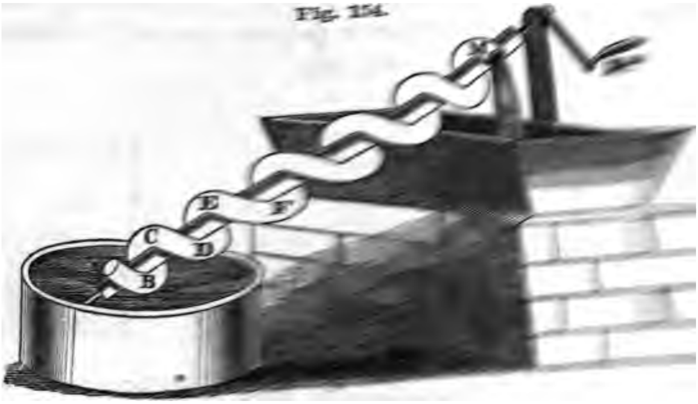
Fig. 153.

In the overshot wheel, the momentum of the stream favors the rotation of the wheel; but in the breast wheel, the momentum of the stream produces pressure on the axis of the wheel.

Sometimes the wheel is placed horizontally, and a stream [illegible] water descending obliquely, strikes upon boards properly [illegible] near the outer rim of the wheel.

267. *Archimedes' screw* is said to have been invented by [illegible] chimedes to aid the inhabitants of Egypt in draining their [illegible] from the overflowings of the Nile. It consists of [illegible] ABCDM, bent into the form of a cork-screw, and placed [illegible] position inclined to the horizon, with its lower end, A, [illegible]

Fig. 154.



in a reservoir of water. By giving [illegible] is carried gradually up the spiral, [illegible]

In order to explain the mode of [illegible]

tion through the water, and approach nearly to the form of the solid of least resistance.

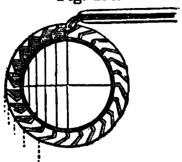
SECTION VII.

HYDRAULIC MACHINERY.

266. Moving water is applied to mechanical purposes chiefly through the medium of wheels. There are three varieties of water-wheels in common use, *the overshot*, *the undershot*, and *breast wheel.*

In *the overshot wheel*, the water is poured over the top, and thus acts principally, though not exclusively, by its weight. A stream of water falls into a bucket at the top of the wheel, and the water is retained until the bucket reaches the bottom of the wheel.

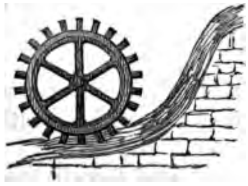
Fig. 151.



When the loaded bucket is directly over the axis of the wheel, it produces merely pressure upon the axis, and has no tendency to give the wheel a rotary motion; but as the wheel is turned, the weight of the water acts upon a lever, whose length is continually increasing until the wheel has made one quarter of a revolution, when the effect of the water is the greatest; and during the next quarter of a revolution, the effect continually decreases until the water is discharged at the bottom. *The total mechanical effect is measured by the quantity of water which descends in the buckets, multiplied by the height through which it falls.*

This wheel is used where the supply of water is scanty and the fall is considerable, as in small mountain streams.

Fig. 152.

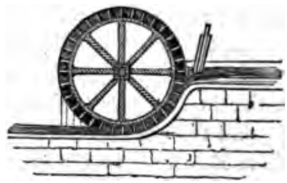


In *the undershot wheel*, float-boards placed at right angles with the circumference of the wheel are employed, and the wheel is turned merely by the force of the current running under it and striking upon the boards. This wheel is used when the supply of water is abundant, but the fall is slight. Ex-

periments show that the most work is done in a given time, when the velocity of the wheel is about half that of the flowing water.

In *the breast wheel*, the water falls down upon the wheel at right angles to the float-boards or buckets. If float-boards are used, the water acts only by its impulse; but if buckets are used, it acts also by the weight of water in the buckets in the lower quadrant of the wheel.

Fig. 153.

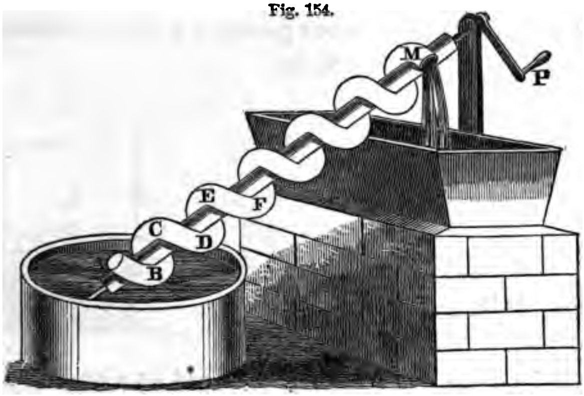


In the overshot wheel, the momentum of the stream favors the rotation of the wheel; but in the breast wheel, the momentum of the stream produces pressure on the axis of the wheel.

Sometimes the wheel is placed horizontally, and a stream of water descending obliquely, strikes upon boards properly attached near the outer rim of the wheel.

267. *Archimedes' screw* is said to have been invented by Archimedes to aid the inhabitants of Egypt in draining their land from the overflowings of the Nile. It consists of a tube, ABCDM, bent into the form of a cork-screw, and placed in a position inclined to the horizon, with its lower end, A, immersed

Fig. 154.



in a reservoir of water. By giving rotation to the screw, water is carried gradually up the spiral, and is discharged at the top, M.

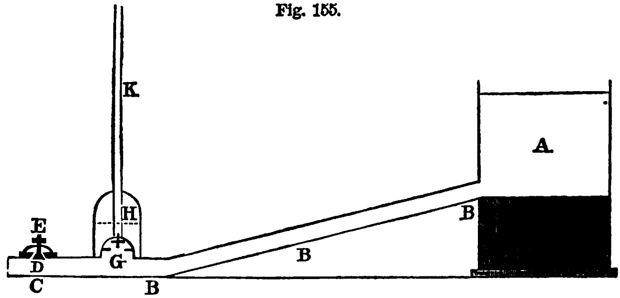
In order to explain the mode of operation of this screw, let

us suppose a small ball to be dropped into the mouth, A; it will fall down the tube until it arrives at the lowest point, B. The point B is so situated that the ball can not move either to one side or the other without ascending. If the screw be now revolved so that the mouth, A, shall be brought to its lowest position, the point B will ascend, and assume the highest position it can have. The ball can not move toward A, because there is a rise in the tube which prevents it. It therefore rolls toward C, and thus in one complete turn of the screw the ball is carried from B to D. In the second turn of the screw it would be carried from D to F, and so on, until at length the ball would be discharged from the upper end of the tube. If a quantity of water were contained in the lowest spiral, it would be carried along the spirals in the same manner as the ball, and at last be discharged at the top. This screw may be made of metal or wood, and two screws may be made to work simultaneously round the same axis.

268. *The hydraulic ram* is a machine for raising water by means of the momentum of a portion of the water that is to be raised, and by it a column of water of small height is made to elevate a column much higher than itself.

Let A represent a reservoir of water, communicating with a pipe, BBB, of which the remoter portion lies nearly horizontally.

Fig. 155.



At C let an orifice be made in the pipe, and let a conical valve, D, be fitted to the orifice so as to close the aperture when the valve is forced upward. To the spindle of the valve is fixed a weight, E, which must be of such a magnitude as to keep the valve down and open, when it is only opposed by the steady

pressure of the water in BB. The water in the cistern, A, flows down the pipe BB, and escapes at the orifice C, as long as this valve remains open; but as soon as it is raised and shut, the motion of the water is suspended. The water, by flowing through the orifice C, soon acquires momentum, which enables it to overpower the resistance of the weight E, and carries the valve D up with it, thereby closing the orifice C. As soon as this orifice is closed, the water again becomes stationary, and its momentum is immediately lost. The weight, E, again falls, thus reopening the orifice, and permitting the water again to flow. Thus the momentum of the water and the weight of the valve alternately preponderate, and the valve is kept in a constant state of oscillation.

But, as often as the momentum of the flowing water is destroyed by the closing of the valve D, a sudden pressure is exerted against the sides of the tube BB. A second valve, G, is therefore placed near the lower end of the pipe BB, which opens upward into an air-chamber, H, having a discharging pipe, K, which is open at both ends, and descends nearly to the bottom of the air-chamber. Whenever the valve D is closed, the suddenly increased pressure of the water opens the valve G, and water enters the air-chamber, H, until the pressure of the contained air overcomes the momentum of the water, when the valve G closes, and that at D opens, permitting the water to make a second pulsation, and thus the machine continues its action without any assistance beyond that of the flowing water; and by the pressure of the condensed air in H the water is forced through the pipe K in a continued stream. A liberal supply of water, such as a running stream or a copious spring, is necessary to maintain the action of this machine, since a much greater quantity of water escapes at the orifice C, between the pulsations, than can be raised in the delivering pipe K.

269. We may judge of the value of this machine, by comparing its useful effect with the power expended. The power expended is the product of the quantity of water used, multiplied by the height through which it falls before it acts on the machine. The useful effect produced is the product of the quantity of water raised, multiplied by the height to which it is elevated. In some experiments carefully made for this purpose,

the expense was found to be to the useful effect as 100 to 64; that is, *the machine employed usefully nearly two thirds of its force.* The valve may be made to close from 40 to 100 times per minute, according to the range of motion allowed it, and the pressure of the water.

Wherever there is a copious spring not more than 50 feet below a neighboring house, a constant stream of water may be delivered at the house by means of this machine. A well of moderate depth, from which the water may be drawn by a siphon, may also be made to answer the purpose of a spring.

270. If a small open tube be substituted for the valve D, we may obtain a continued jet of water directed perpendicularly upward; and *upon this jet, a ball or cylinder of cork may be permanently sustained.* The jet strikes the cylinder a little on one side of the axis, and gives it a rapid rotation about its axis. The support of the cylinder is due,

1. To the direct impulse of the water, which counteracts the gravity of the cork.

2. The cork is prevented from falling off laterally, by the operation of that principle which has been explained on page 146: that a stream of water drags along with it the air in contact with it, and the neighboring air presses in to supply its place; that is, the air from all sides presses toward the jet of water, and holds the cork in contact with the stream.

3. The cork is rendered more steady in its position, by the operation of another principle illustrated by the gyroscope, viz., the tendency of all rotating bodies to maintain invariably the same plane of rotation.

If we condense air in a close vessel, and allow it to escape through a small pipe directed perpendicularly upward, a light pith ball may be sustained upon this jet of air, precisely as in the experiment with the jet of water.

BOOK THIRD.

PNEUMATICS.

SECTION I.

MECHANICAL PROPERTIES OF AIR.

271. *Pneumatics treats of the mechanical properties of fluids in the form of air.*

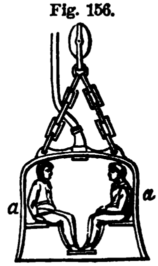
At present we shall confine ourselves to the properties of atmospheric air.

272. *Air is material.* The two essential properties of matter are extension and impenetrability. *Air obviously has extension.* Thus, we may have a cubic inch or a cubic foot of air. That *air has the property of excluding all other matter from the space which it occupies,* is proved by the following experiments. If we depress an inverted tumbler in water, we shall find that the water will not rise so as to fill the vessel.

If a piston be forced against the air confined in a perfectly close cylinder, it can not be made to reach the bottom of the cylinder.

The diving-bell exhibits this principle on a large scale. A large hollow vessel, *a a*, is sunk in the water by means of weights, with its mouth downward. Seats and other conveniences are provided within for the accommodation of workmen, and the whole apparatus is let down to the bottom of the sea. Notwithstanding the open mouth, and the pressure of the sea, the water is effectually excluded by the air contained in the bell.

Fig. 156.



273. *Air has inertia.* Wind is simply air in motion. The force which moves a wind-mill is the momentum of the wind acting on the sails.

A ship is carried across the ocean, and the sea is raised into waves by the inertia of the atmosphere in motion. Houses and

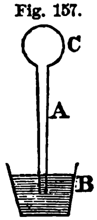
forests are overturned by the force of the hurricane. It is the inertia of the atmosphere which enables birds to fly. In a space void of air, even if birds could live, they would not have the power of flight.

274. *Air is an elastic fluid.*

Thus, when an inflated bladder is compressed, it restores itself to its former state as soon as the compressing force is removed.

When a diving-bell is sunk in the sea, the water, although it can not displace the air, compresses it, and rises to a certain height within the bell. When the bell is raised to the surface, the air expands, and recovers its former volume. Take a glass tube with a large bulb, C, the lower end being open, and dipping into a vessel of water, B. If we warm the bulb, the air is at once dilated, and a portion of it escapes. If we cool the bulb, the included air collapses.

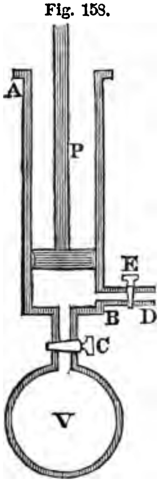
Fig. 157.



275. THE AIR-PUMP.

The principle of the air-pump may be illustrated by means of a glass vessel with a small exhausting syringe. Let AB represent a cylinder having a solid piston, P, moving in it air-tight. Let a tube, having a stopper, C, connect the cylinder with a vessel, V, from which it is desired to extract the air. Let another small tube, D, furnished with a stopper, E, be connected with the bottom of the cylinder.

Fig. 158.

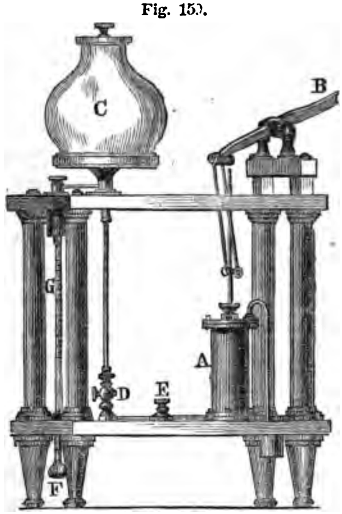


If, when the stopper E is closed, and that at C is open, the piston, P, be raised from the bottom of the cylinder, the air in the vessel V will expand so as to fill the entire space below the piston. Let now the stopper C be closed, and that at E be opened. Upon forcing down the piston, the air which fills the cylinder will be expelled from the tube D through the open stopper E. Let E be again closed, and C opened, and let the same process be repeated, another portion of air will be expelled from the vessel V. Thus, at each operation, the air in the vessel becomes more

and more rarefied. These successive operations are most conveniently performed with an air-pump.

276. *An air-pump is an instrument for exhausting the air from a close vessel.* It consists of an exhausting syringe, A, mounted so as to be worked with a lever, B, and communicating by a tube with a glass vessel, C, in which may be placed the objects upon which we wish to experiment. The vessel, called a receiver, has an edge carefully ground, and rests upon a brass plate, which is also ground to a smooth plane surface, the edge of the vessel being smeared with oil, in order to insure a closer connection with the plate. The tube is provided with a stopper, D, by which the communication between the receiver and the syringe can be interrupted or restored at pleasure.

Fig. 159.



There is another stopper, E, by which a communication can be made at pleasure between the interior of the receiver and the external air. Instead of the stoppers, supposed to have been used in Art. 275, self-acting valves are employed.

277. *A valve is a contrivance which permits a fluid to pass in one direction, but prevents it from passing in the opposite direction.* It is sometimes made in the form of a conical stopper, fitting a corresponding cavity. Sometimes it is merely a strip of oiled silk or leather tied over a small orifice. When the air presses from without, it forces the oiled silk down close against the opening, so as effectually to stop the passage; but when the air presses from within, it lifts the oiled silk, and the air readily escapes. There is a valve in the bottom of the exhausting cylinder, A, opening upward, another in the piston itself, and a third in the top of the cylinder, all opening upward. When the piston is raised, the valve at the bottom of the cylinder is opened by the elasticity of the air in the receiver; and when the piston

is depressed, the valve is closed by the elasticity of the compressed air in the cylinder. When the piston is depressed, the valve in the piston is opened by the elasticity of the air compressed beneath it, and the air rushes through the valve. When the piston is again raised, the valve in the piston is closed by the pressure of the air above it; the valve in the top of the cylinder is opened by the elasticity of the air compressed beneath it, and the air is expelled from the cylinder. Thus each time the piston is elevated, a portion of air is withdrawn from the receiver.

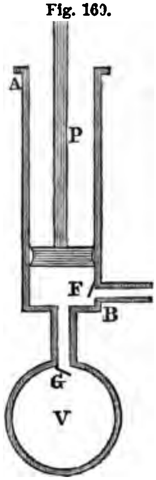
278. *The exhaustion of the receiver proceeds in a geometrical ratio.* If we suppose the volume of the exhausting cylinder to be $\frac{1}{10}$ of the entire volume of the receiver and cylinder combined, then, at the first stroke of the piston, $\frac{1}{10}$ of all the air in the receiver will be expelled, and $\frac{9}{10}$ will remain. At the second stroke, $\frac{1}{10}$ of the remainder—that is, $\frac{9}{100}$ of the original air—will be expelled, and $\frac{81}{100}$ will remain. At the third stroke, $\frac{1}{10}$ of the remainder—that is, $\frac{81}{1000}$ of the original air—will be expelled, and $\frac{729}{1000}$ will remain. Thus, at each stroke, we expel $\frac{1}{10}$ of what remained after the preceding stroke. By continuing this process, provided there is no leakage, the rarefaction may be carried to any required extent; but *an absolute vacuum can not be produced*, because some air must always remain in the receiver. After each stroke of the piston, there still remains $\frac{9}{10}$ of the air which was in the receiver before the stroke.

279. To indicate the extent to which the rarefaction is carried, *a mercurial gauge* is provided, similar to a barometer. The external atmosphere presses on the surface of the mercury in the cistern F, while the column of mercury in the tube G is pressed downward by the rarefied air in the receiver. Hence the height of the column sustained in the tube G, indicates the difference between the pressure of the external air and the air in the receiver. If the exhaustion were perfect, the gauge would usually stand at about 30 inches. When one half of the air is exhausted from the receiver, the gauge should stand at 15 inches, and so forth.

280. *The condenser.*

This instrument differs from the exhausting syringe chiefly in the direction in which the valves are placed, the valves opening downward instead of upward. Let AB represent a cylinder

Fig. 160.

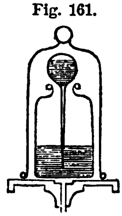


having a piston moving in it air-tight. When the piston is drawn upward, the cylinder is filled with air proceeding from the external atmosphere, through the valve F. When the piston is pressed downward, the valve F is closed by the pressure of the air within, while the valve G is opened, and the air which filled the cylinder AB is forced into the vessel V. On raising the piston again, the valve G is closed by the pressure of the air within the vessel V, the valve F is opened by the pressure of the external air, and the cylinder is filled with air. When the piston is pressed downward, this air is forced into the vessel V as before, and so on at each stroke of the piston. *The condenser will cease to operate when the air at the bottom of the depressed piston has not sufficient elasticity to lift the valve which opens into the receiving vessel.*

281. With these instruments we can demonstrate the properties of air.

The elasticity of air may be shown with an empty flask inverted with its mouth below the surface of the water contained in a vessel, and the whole placed under the receiver of an air-pump. If we exhaust the air within the receiver, the air contained in the flask expands, and a portion escapes through the water. If we readmit the external air, the water will rise, and occupy the principal portion of the flask.

Fig. 161.

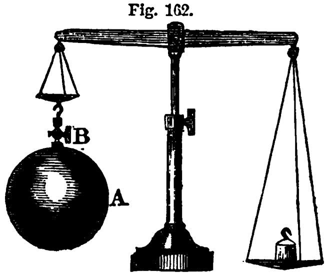


If a vessel containing soap-bubbles be placed under the receiver, and the air be exhausted, the bubbles will rapidly increase in volume, owing to the expansion of the air which they contain.

282. *Air has weight.*

Let a glass globe, A, *Fig.* 162, having a small neck provided with a stopper, B, be emptied of

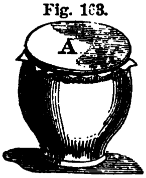
Fig. 162.



its air, and let it be accurately weighed. Let the stopper be now opened, the air be readmitted, and let the globe be again weighed. It will be found to be heavier than before. Let the condenser be next attached to the mouth of the globe, and let air be compressed in it, so as to make it contain twice as much air as before, and let it be again weighed. The increase of weight produced in the latter case will be exactly equal to the increase of weight produced by readmitting the air into the empty globe. From these experiments we find that *a cubic foot of air, at the temperature of* 60° *F., and pressure of* 30 *inches, weighs* 536 *grains*, or about $1\frac{1}{5}$ ounce.

283. *Since air has weight, it must exert pressure on all objects immersed in it.* In most cases this pressure is not felt, because it takes place equally in all directions. It is shown in the force with which the receiver is held to the plate of the air-pump.

Fig. 163.

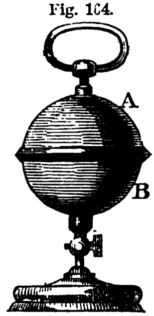


If we take a small jar open at both ends, and, having placed it on the pump-plate, lay the palm of the hand upon the mouth of it, when we exhaust the air the hand is pressed down with great force.

If we tie over the open end of the jar a piece of bladder, A, and allow it to dry, on exhausting the air from the jar the bladder usually bursts.

284. *The atmosphere presses equally in every direction.* This is proved by the Magdeburg hemispheres. This apparatus consists of two hollow brass hemispheres, A, B, with their edges ground to a plane surface, and brought close together, with a thin film of oil between them. One of the hemispheres may be screwed upon the plate of the air-pump, so that the air may be exhausted from between the two hemispheres. When this is done, the two hemispheres are pressed together with a force equal to the difference between the pressure of the external air and the pressure of the rarefied air within. The two hemispheres adhere with equal force, in whatever position they may be held. If they are 4 inches in diameter, the area of their section will be $12\frac{1}{2}$ square inches, and the force with which they are held to-

Fig. 164.



gether would be 180 pounds, if the air were all exhausted from between them.

This apparatus receives its name from the inventor of the air-pump, Otto von Guericke, the burgomaster of Magdeburg, by whom this experiment was first tried in 1654. He employed two strong hemispheres of brass, about one foot in diameter, and when the air was exhausted from between them, it required the force of more than 30 horses to draw them asunder.

Take a cubical bottle made of very thin glass, and fit to its neck a cap with a valve opening outward. Place the bottle under the receiver of the air-pump, and exhaust the air. The air will be drawn from the bottle as well as the receiver, and the bottle will be uninjured; but if we readmit the air into the receiver, the valve will prevent the return of the air into the bottle, and the bottle will be crushed by the external pressure.

285. *The amount of the pressure of the atmosphere* may be measured by attaching a load, A, to a piston, B, which moves freely in a cylinder, C, from which the air may be exhausted by connecting it with the air-pump. If the piston be $4\frac{1}{2}$ inches in diameter, it will support a load of over 200 pounds when the air is entirely exhausted from the cylinder. By the same arrangement, we are able to exhibit in a striking manner the elasticity of the air. If, when the air is partially exhausted, the loaded piston be forced from its condition of equilibrium by the pressure of the hand, on removing the hand the piston will oscillate to and fro like a pendulum.

Fig. 165.

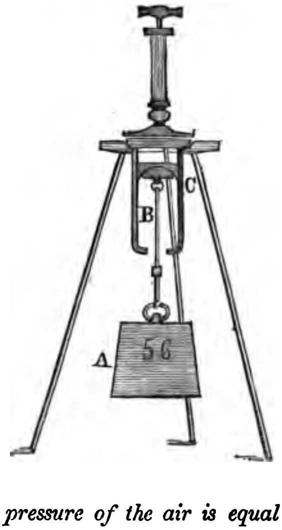
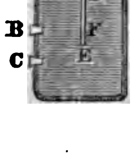
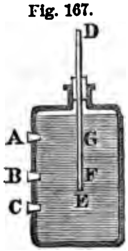


Fig. 166.



286. That *the lateral pressure of the air is equal to its downward pressure*, is proved by Mariotte's receiver. This consists of a glass bottle filled with water, and having in its side three small holes, A, B, C, closed by plugs, which may be removed at

Fig. 167.



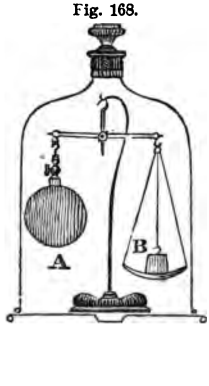
pleasure. The neck of the bottle is closed with a cork, through which passes a tube, DE, open at both ends, and terminating a little above the lower orifice, C. If we remove the plug B, the water will escape until the liquid in the tube DE stands at the point F, which is on the same level as B. Hence we conclude that the pressure of the air at B, in a horizontal direction, is equal to the pressure at F, in the tube DE, in a vertical direction.

If we close the hole B and open A, the equilibrium will be destroyed; for the atmospheric pressure which acts on the water at A, from without inward, is greater than the pressure which forces the water outward, by the weight of a column of water whose base is the orifice A, and whose height is AB. Air will therefore enter the bottle, until the water, rising in the tube DE, reaches the point G, which is on the same level as A, when the equilibrium will be again established.

If we close both openings A and B, and open the hole C, the water will escape; for the atmospheric pressure at C inward, will be less than the pressure which urges the liquid to escape, by the weight of a column of water whose height is the vertical distance between the hole C and the level of the water in the tube. The water in the tube will therefore fall; and as there can be no equilibrium when the air reaches the end of the tube (because the opening C is below E, the end of the tube), air will enter the bottle through the end E, and the water will continue to flow until the surface of the water has fallen to C.

287. A solid immersed in a fluid loses a portion of its weight.

Fig. 168.



Hence *every substance weighs less in air than in vacuo.* To prove this, attach a ball of cork, or a hollow glass globe, A, to one arm of a balance, and counterpoise it with a weight, B. Under an exhausted receiver the cork descends, and appears to be the heaviest. Hence it is claimed, not entirely without reason, that "*a pound of cork is heavier than a pound of lead.*"

A body which has the same density as atmospheric air will remain suspended in it;

if it be lighter than air, it will rise like cork in a vessel of water. Air-balloons are founded upon this principle.

288. *The resistance of the air diminishes the velocity of falling bodies*, and this diminution is greatest for bodies of least density; hence those bodies which we call light, fall slower than dense substances. Thus, if we drop a feather and a piece of lead at the same instant, the lead will reach the floor while the feather is yet falling; but let them fall in the exhausted receiver of an air-pump, and both will reach the bottom at the same time. In order that the time of fall may be appreciable, the receiver for this experiment should have a length of several feet.

Fig. 169.

The following experiment illustrates the same principle. Take a retort containing a little water, and boil the water over a spirit lamp. The vapor of the water will gradually drive out the air; after which, cork the retort, and then, by cooling the water, condense the vapor, producing a partial vacuum. The water, being now agitated, will fall like lead upon the glass, and emit a ringing sound.

289. *The atmosphere is the ordinary medium through which sound is transmitted to the ear.* The sound transmitted through rarefied air is much feebler than that transmitted through dense air. Under the receiver of an air-pump, introduce a bell upon which a hammer may be made to strike for several minutes in succession by means of a spring. Place the bell upon a soft cushion, so as to prevent the vibrations from being communicated to the pump-plate, and let the receiver be exhausted. As the air becomes more rarefied, the sound grows more faint, until it becomes scarcely audible, although the hammer is seen to strike upon the bell. If we readmit the air into the receiver, the sound will gradually recover its original intensity.

290. *Air is necessary to the support of animal life.* If we place a bird beneath the receiver of an air-pump, a few strokes of the piston will cause it to make convulsive struggles, and death will soon ensue unless air be admitted. Most warm-blooded animals expire when the air is only partially rarefied; but cold-

blooded animals endure the vacuum of an air-pump for a long time.

Air is necessary to the support of combustion. If a lighted candle be placed under a receiver, the flame expires as soon as the air is withdrawn. The smoke also descends to the bottom of the receiver, since there is no longer any thing to sustain it.

Air is included in the pores of most bodies.

If an egg be dropped into a deep jar of water, and covered with a receiver, bubbles of air will ascend through the water as soon as the exhaustion commences.

A glass of porter placed beneath an exhausted receiver is immediately covered with foam. Common spring water, treated in the same manner, emits a considerable quantity of air, which rises in small bubbles.

SECTION II.

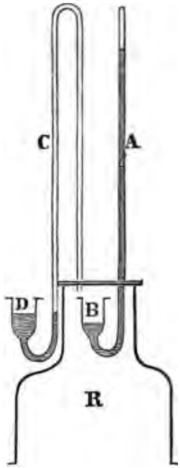
BAROMETER. WEIGHT AND PRESSURE OF THE ATMOSPHERE.

291. The most convenient instrument for measuring the pressure of the air is *the mercurial barometer.* Take a glass tube, AB, more than 30 inches long, open at one end, and closed at the other. Fill the tube with mercury, and apply the finger to the open end so as to prevent the escape of the mercury; then invert the tube, and plunge its open end into a cistern of mercury, C. On removing the finger, the mercury will subside until the top of the column stands about 30 inches above the surface of the mercury in the cistern. Such an instrument is called *a barometer.* The space above the mercury is called *the Torricellian vacuum,* from Torricelli, an Italian philosopher who first tried the experiment.

Fig. 170.

292. *The mercury in the barometer tube is sustained by the weight of the atmosphere* acting upon the surface of the mercury in the cistern. This is shown by *the receiver with two barometers.* This instrument consists of a glass receiver, R, fitted to the air-pump,

Fig. 171.



and closed at the top by a metallic plate, to which are fitted two siphon tubes. A is a bent tube about three feet long, filled with mercury, and terminating at the open end in a vial-shaped vessel, B, which is included in the receiver. This tube passes air-tight through the plate on the receiver. C is a second tube, bent in three branches, and terminates at one end in an open vial-shaped vessel, D, while the other end communicates with the receiver by passing through the metallic plate at the top. If we pour mercury into the vial D, it will rise to the same level in the branch C, and the communication between the interior of the receiver and the external air will be interrupted.

293. The receiver being placed upon the plate of the air-pump, and the air exhausted, the mercury will descend in the tube A until it stands at nearly the same level as in the vial B; and it will ascend in the tube C, toward the bend at the top, until it stands about 30 inches above the mercury in the vial D. If we readmit the air into the receiver, the mercury will rise in the tube A, and fall in the tube C.

Hence we see that *the atmosphere presses with a force sufficient to maintain the mercury in the tube* A *at a height of nearly* 30 *inches;* that is, the amount of its pressure on any surface is equal to the weight of a column of mercury whose base is the given surface, and whose altitude is about 30 inches.

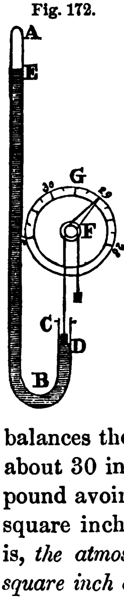
294. There are many *different forms of the barometer*, such as *the straight tube*, *the siphon*, *the wheel barometer*, etc.

The height of mercury to be measured, is that of the top of the column in the tube, above the surface of the mercury in the cistern. Now, whenever the mercury in the tube rises, the surface in the cistern must fall, and vice versa, since whatever mercury enters the tube must leave the cistern. Thus *the level of the mercury in the cistern is continually fluctuating.* To obviate this inconvenience, the scale by which the height of the mercury is measured, is sometimes made movable, so that at each observation the lower extremity may be brought into contact with the

surface of the mercury in the cistern. In some barometers the scale is fixed, but the level of the mercury in the reservoir may be adjusted by turning a screw, which elevates or depresses the bottom of the reservoir. If the reservoir be very large, the fluctuations of the surface of the mercury contained in it will be very small, and are often neglected.

295. A common form of barometer is *the wheel barometer.* The tube, ABC, is bent in the form of a siphon, and an iron float is placed upon the mercury at D, which rises and falls with the mercury. Since the two arms of the siphon have the same diameter, the changes of altitude of the mercury at D must be equal to those at E. The float, D, is connected by a string with a wheel, F, which carries an index that traverses a dial-plate, G, which is graduated to inches and fractions of an inch. Thus, as the mercury rises or falls in the tube AB, the index F moves backward or forward on the dial-plate G.

Fig. 172.



This form of barometer is much less accurate than the straight-tube barometer, and is not recommended for use.

296. The height of the column of mercury which balances the atmospheric pressure at the surface of the earth is about 30 inches. Now two cubic inches of mercury weigh one pound avoirdupois; hence a column of mercury whose base is a square inch, and height 30 inches, will weigh 15 pounds; that is, *the atmosphere presses with a force of 15 pounds upon every square inch of surface upon which it rests.*

The surface of a human body of average size measures about 2000 square inches. Such a body, therefore, sustains a pressure from the atmosphere amounting to 30,000 pounds, or *nearly* 15 *tons.*

If the pressure of the atmosphere be so great, it might be supposed that delicate bodies would be crushed and destroyed by it, whereas they seem entirely unaffected by it. This results partly from the equality of the pressure on all sides, and partly from the resistance produced within by the elasticity of the contained air. Animals are neither crushed nor obstructed in their movements by the enormous pressure to which they are subjected, because the atmosphere presses upon their bodies equally in every

possible direction, and because they sustain the same pressure internally as externally.

297. When the elastic force of a gas or vapor is very considerable, it is usual to estimate it in *atmospheres;* thus, when we say steam has a pressure of two atmospheres, we mean that its elastic force would sustain a column of 60 inches of mercury, or that it exerts a pressure of 30 pounds on each square inch of the vessel which contains it. If it is said to have a pressure of five atmospheres, we mean that it exerts a pressure of 75 pounds on the square inch, and so on.

298. *Fluctuations of the barometer.* The barometric column is subject to *two species of fluctuations,* one of which takes place *at regular periods,* and the other may be called *accidental.* If we observe the height of the barometer at each hour of the day for a long period of time, and take the average of all the observations at the same hour, we shall find that the column attains its greatest height from 8 to 9 in the morning, from which time it falls until 3 or 4 in the afternoon. It then begins to rise, and attains another maximum at 9 or 10 in the evening. The amount of this diurnal variation at the equator is $\frac{12}{100}$ of an inch, and diminishes as we recede from the equator.

299. The *accidental* or *non-periodic variations* of the barometer are much greater in amount. The greatest height which the barometer kept at the Paris Observatory has been known to attain is 30.7 inches, and the lowest is 28.2 inches; the difference being 2.5 inches. The entire range of the barometer at New York in a period of 7 years has been 2.25 inches.

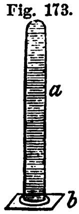
The non-periodic variations of the barometer have been long regarded as indicating *changes in the weather,* and hence the barometer is sometimes called *a weather-glass.* On some barometers we find the words Rain, Fair, Changeable, Frost, etc., engraved upon the scale; but these terms are only calculated to mislead, for the absolute height of the mercurial column varies with the elevation of the instrument above the sea. The following rules are more reliable.

The rise of the mercury generally indicates the approach of fair weather; a fall of the mercury indicates the approach of a storm. When the mercury falls very suddenly and very low, a high wind is sure to succeed.

300. *A barometer may be constructed with any other liquid than mercury.* Since mercury is 13 times heavier than water, the pressure of the air would sustain a column of water in a tube to the height of about 34 feet. Such an instrument is called *a water barometer*, and any change which would produce an oscillation of a tenth of an inch in the column of mercury, would produce an oscillation of more than an inch in the column of water. Several water barometers have been constructed, but they are very unwieldy, and can not be easily transported from place to place. Moreover, vapor rises from the water and fills the top of the tube, impairing the vacuum and depressing the column of water. A barometer having a tube filled with *sulphuric acid* has recently been constructed for the Smithsonian Institution. As the specific gravity of sulphuric acid is 1.85, the column of acid will ordinarily stand at the height of about 18 feet. All such instruments are expensive and unwieldy, and no other fluid than mercury is therefore used for barometers, except for purposes of curiosity.

301. There are many simple experiments which illustrate the principle of the barometer. If we take a tall jar, and, having filled it full of water, invert it in a reservoir, the liquid will remain suspended in the jar. This is caused by the downward pressure of the air on the water in the reservoir, which pressure is transmitted to the water in the jar, and this pressure is sufficient to sustain a column of water 34 feet in height.

Fig. 173.

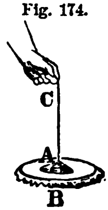


If we take a tube, *a*, an inch or two wide, and two or three feet long, closed at one end and open at the other, and, having filled it entirely with water, place over its mouth a slip of paper, *b*, and invert the tube, the column of water will be supported by the pressure of the air upon the paper.

It is not necessary that a piece of paper should be used, provided that the opening be not too large. Take a tube whose bore is about a third of an inch, and open at both ends. Fill it with water, and close the top with the finger; the water will not flow out, though the tube be held vertically; but on removing the finger the water will escape.

302. The phenomena ascribed to *suction* are merely the effects of atmospheric pressure. If a piece of moist leather, A, be

Fig. 174.

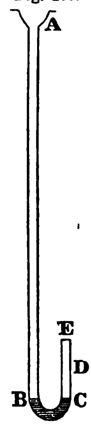


brought in close contact with a stone, B, having a smooth surface, it will adhere firmly to it; and if a cord, C, be attached to the leather, the stone may be lifted by it. If the air is entirely excluded from between the leather and the stone, the atmosphere will press their surfaces together with a force amounting to 15 pounds on each square inch of the surface of contact.

303. *Mariotte's Law.*

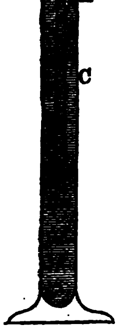
The volume of a given weight of air is inversely as the pressure upon it. To prove this law, take a tube, ABE, bent in the form of a siphon, with unequal arms, having the shorter arm closed and the other open. Introduce into the bend of the tube a small quantity of mercury, which shall stand at the same level, B, C, in both branches of the tube; then add to the longer arm, AB, a column of 30 inches of mercury. The mercury in the shorter arm will rise to D, and ED will be one half of EC; that is, *by doubling the pressure upon a confined mass of air, it is reduced to one half of its original volume.*

Fig. 175.



The same law holds true for rarefied air. Take a long tube, AB, closed at A, and open at B; depress it in a vessel of mercury, C, with a few inches of air in the top of the tube. If the tube be elevated, the included air will dilate; and when the air has expanded to twice the volume which it had when the mercury in the tube stood at the same level as in the vessel, the length of the mercurial column, DE, in the tube will be 15 inches. But the pressure which this air sustains is 30 inches, minus the height of DE, or 15 inches; that is, *under half the ordinary pressure, the volume of a given mass of air is doubled.*

Fig. 176.



This law has been verified experimentally until the air has been condensed 27 times, and rarefied 112 times; and the law is found to be rigorously exact.

304. *Density of the atmosphere.* The weight of a

cubic foot of mercury is 10,517 times greater than that of a cubic foot of air; and, since the average height of the barometric column is about $2\frac{1}{2}$ feet, *if the atmosphere were throughout of the same density as at the surface of the earth, it would rise to a height of* 26,000 *feet.* But the density of the atmosphere diminishes rapidly as we ascend from the surface of the earth; for if we suppose the atmosphere to consist of a series of layers or strata placed one above the other, each successive stratum, as we ascend, will sustain a weight less than those below it. The first stratum of atmosphere is compressed by the entire weight of the atmosphere above it; the next stratum is compressed by the weight of the whole atmosphere, except that of the first two strata; the third stratum is compressed by the weight of the whole atmosphere except the first three strata, and so on. Now, since the density of air is proportional to the force which compresses it, the density of the lowest stratum must be greater than that of the second; the density of the second greater than that of the third, and so on.

It is computed that at the height of 4.30 miles, the density of the air is one half what it is at the earth's surface; at the height of 8.11 miles, the density is one fourth what it is at the earth's surface; at the height of 11.89 miles, the density is one eighth, etc.; or, in round numbers, we may say that *the density of the atmosphere is reduced one half for each ascent of* 4 *miles.*

305. *Height of the atmosphere.*

Since the density of the air diminishes as the compressing force decreases, it might be inferred that *the atmosphere would extend to an unlimited height.* But each particle of air has weight; and when the air becomes so far rarefied that the mutual repulsion of the particles is only equal to their weight, *no farther expansion can take place.* At this point, therefore, will be the limit to the height of the atmosphere. This limit can not be certainly determined, but it is inferred from the duration of twilight that *at the height of* 50 *miles, the atmosphere becomes well-nigh inappreciable.*—*Ivory,* Phil. Trans., 1823, p. 457.

306. *Altitudes measured by the barometer.* By comparing the height of the barometric column at two stations, one of which is above the other, we can ascertain the weight of a column of air extending from the lower to the higher station. If the barom-

eter at the lower station stands at 30 inches, and at the higher station 20 inches, it follows that the weight of air between the two stations is one third of the entire quantity extending from the lower station to the summit of the atmosphere.

If the atmosphere were throughout of uniform density, the barometer would therefore afford an easy means of measuring altitudes; but since the air expands as the height increases, the heights of columns of air are not proportional to their weights. The density of each stratum of air is affected not merely by the pressure of the strata above it, but also by its own temperature. As the temperature decreases, the air becomes less rarefied, and it requires a greater density to support the same incumbent pressure. Formulæ have been discovered by which the change of altitude may be computed when we know the change of pressure indicated by a barometer, as well as the state of the thermometer.

M. Gay Lussac, in his celebrated balloon ascent in 1805, found his barometer to indicate 12.9 inches, the temperature being 15° Fahrenheit. The height of his balloon above Paris is computed to have been 22,900 feet.

307. *Altitudes determined by the boiling point of water.* The boiling point of water depends upon the pressure to which it is subjected. Thus, if a glass of warm water be put under the receiver of an air-pump, and the air be exhausted, the water will commence boiling, and continue until the temperature goes down to 67 degrees. Indeed, the same phenomena are observed (although in a less striking degree) at all temperatures down to the freezing point of water. If a small quantity of water be placed in a shallow dish, and a vessel of sulphuric acid be placed by its side for the purpose of absorbing the vapor which rises from the water, in a good vacuum the water will boil freely until it is entirely frozen.

By observing the boiling point of water, we are enabled to determine the height of mountains. As we ascend from the level of the sea, the pressure of the air decreases, and water boils at a lower temperature. *The boiling point sinks one degree in an ascent of 520 feet from the level of the sea;* and hence, if we know the temperature of boiling water, the altitude of the station may be computed.

308. Many substances exist in the liquid condition merely in consequence of the pressure of the air. Take a glass tube filled with water, and invert it in a jar of water. Introduce into the tube a little sulphuric ether, which will rise to the top of the tube. If we place it under a receiver and exhaust the air, the ether will assume the gaseous form, and fill the entire tube. If we readmit the air, the ether will return to the liquid state.

309. *Pneumatic Paradox.* In some cases, *when a current of air is impelled against a light surface, like a slip of paper, the paper, instead of being blown off, appears to be attracted by the current of air.* Take a metallic disk two or three inches in diameter, perforate it in the centre, and fix it on the top of a small tube; then let a card be held before the disk; when a current of air is impelled through the tube, the card, instead of being blown away, will be held firmly to the disk.

This effect is not due to *a rarefaction of air by the heat of the mouth*, for the experiment succeeds equally well when the air is impelled by a bellows. Neither is it due to *currents of air diverging from the disk and striking against the back of the card*, for the experiment succeeds equally well when the arrangement is such that these currents can not strike the back of the card.

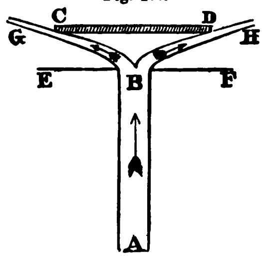
310. This effect is due to a rarefaction produced mechanically by the issuing stream of air. A stream of water in rapid motion drags along with it a portion of the air that is in contact with it, and, in like manner, a stream of air carries along with it the neighboring air. This is seen in the following experiment.

Make a cylindrical tube of tissue paper, about $\frac{3}{4}$ inch in diameter and 6 inches long, and fit to one end of it a plug of wood, having in its centre a hole $\frac{1}{4}$ inch in diameter. On blowing forcibly through the hole, the paper tube, instead of expanding, will collapse. The stream of air whose diameter is $\frac{1}{4}$ inch, rushing through the paper tube whose diameter is $\frac{3}{4}$ inch, drags along with it the adjacent air, produeing a partial rarefaction; and the external air, pressing against the sides of the tube, causes a collapse. The same principle explains the pneumatic paradox.

A column of air issuing from the tube AB, *Fig.* 177, and being interrupted in its course by the plate CD, spreads out upon a

conical surface, GBH, containing the cavity BCD. At the commencement of the experiment, this cavity is filled with air of the ordinary density; but when the air is violently impelled along the sides BG, BH, the air contained in the space BCD is dragged along by the stream, and a rarefaction is produced in the space BCD. The pressure of the atmosphere acting upon the surface of the plate CD therefore crowds it toward the orifice, and the stronger is the blast, the stronger is the pressure of the plate CD against the orifice of the tube.

Fig. 177.



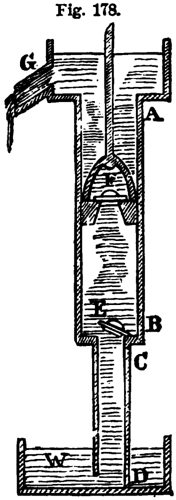
SECTION III.

MACHINES FOR RAISING WATER.

311. *The suction pump.*

This instrument consists of a tube, CD, called the suction pipe, which descends into the well, W, and has at the top, a valve, E, opening upward. Attached to the top of this tube is a large syringe, AB, called the barrel, similar to the exhausting syringe described in Art. 275; and there is a valve, F, in the piston opening upward. At the commencement of the operation, the suction pipe is filled with air to the level of the water in the well; but by means of the syringe, a portion of the air is drawn out of the pipe. As soon as the water within the pipe is relieved from the atmospheric pressure, the weight of the atmosphere, acting upon the surface of the watèr in the well, forces the water up the pipe; and if the exhaustion be sufficient, the water will rise until it passes through the valve E at the top of the suction pipe. This valve, opening upward, prevents the re-

Fig. 178.



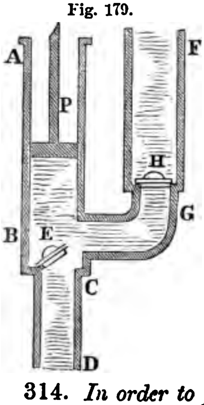
turn of the water, since the weight of the column above it tends to keep it closed. When the piston descends, the valve E is closed, and the valve F in the piston is opened, so that the water passes through the piston. When the piston is raised, the valve F is closed, and the column of water above the piston is lifted to the spout G. At the same time, the pressure of the atmosphere on the water in the well, causes more water to rise in the barrel under the piston.

312. Since the atmospheric pressure is only capable of supporting a column of 34 feet of water, *the piston must be placed at a height of less than 34 feet above the surface of the water in the well*, otherwise the atmospheric pressure would not keep the water in contact with the piston.

Although the pressure of the atmosphere sustains a column of water in the suction pipe, yet *this does not diminish the power required to lift the water from the well*, for the atmosphere also presses upon the upper surface of the column with an exactly equal force; that is, the downward pressure of the atmosphere is exactly equal to the upward pressure; and *the weight of the entire column of water, extending from the surface of the well to the discharge pipe*, G, *must be lifted by the power which works the pump.*

313. *The forcing pump* has a suction pipe, CD, similar to the suction pump, but the piston, P, has no valve. There is a valve at E opening upward. Connected with the barrel, AB, is another tube, FG, called the forcing pipe, having at its base a valve, H, opening upward. When the piston is raised, the valve E is opened, and the water rises from the suction pipe into the pump barrel. When the piston is pressed downward, the valve E is closed, and the water is forced through the valve H into the force pipe; and at each stroke of the piston the same operation is repeated.

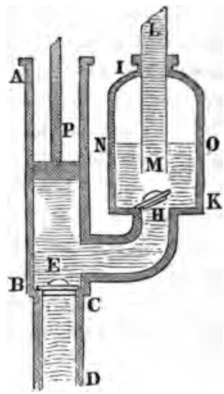
Fig. 179.



314. *In order to produce a continued flow of water in the force pipe, an air-vessel is often attached to the forcing pump*, as shown in *Fig.* 180. When the piston descends, the water is driven through the valve H into the vessel IK, which contains air. The

pipe LM, open at both ends, descends into this vessel, and terminates near the bottom. The water which is forced into this vessel rises in it to a certain level, NO, while the remainder of the vessel is filled with condensed air. The pressure of the air forces the water through the tube LM, from the top of which the water issues in a constant stream.

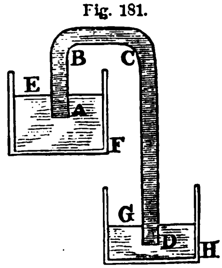
Fig. 180.



The fire-engine consists mainly of two force pumps worked by a common handle. While one piston is ascending in one barrel, the other piston is descending in the other barrel, by which means an uninterrupted stream of water is forced into the air-vessel, and escapes through the discharging pipe.

315. *The siphon* is a bent tube, having two branches of unequal length, and *is employed for transferring a liquid from one vessel to another*. Let ABCD be a bent tube open at both ends, and let the shorter leg, AB, be immersed in the liquid, EF, which is to be transferred to the vessel GH. If the air be withdrawn from the tube, the liquid in the vessel EF will be forced by the pressure of the atmosphere up the pipe AB; it will fill the entire tube, and will continue to flow through the siphon, as long as the level of the liquid in the vessel EF is above the level of the liquid in the vessel GH. It is evident that the height of the bend B of the siphon above the level of the liquid in EF, must not exceed that at which the atmospheric pressure would sustain a column of the liquid. If the liquid be mercury, the height of B above EF must be less than 30 inches; if it be water, the height must be less than 34 feet.

Fig. 181.



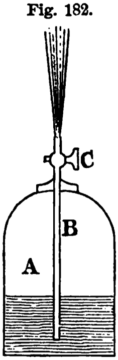
The amount of the force which impels the liquid through the siphon may be estimated as follows: The column extending from E to B is pressed upward by the weight of the atmosphere acting upon the surface of the liquid in EF. This force is opposed

by the weight of the column of liquid in the siphon extending from E to B; hence the total pressure acting at B, in the direction BC, is the weight of the atmosphere, *minus* the weight of the column BE. So, also, the total pressure acting at C, in the direction CB, is the weight of the atmosphere, *minus* the weight of the column CG. Hence the liquid is urged in the direction BC by a force equal to the excess of the weight of CG above that of BE. If the height of B above the surface of the liquid in the two vessels were the same, the liquid could not flow in either direction; but it will always flow toward that vessel in which the level of the liquid is lowest.

Sometimes a suction pipe is attached to the siphon for the purpose of exhausting the air from the siphon with greater facility.

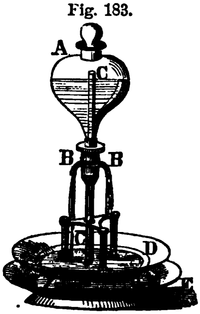
316. *The fountain with condensed air* consists of a stout vessel, A, usually of brass, partly filled with water, above which the air is condensed by means of the condensing syringe. A tube, B, open at both ends, extends below the surface of the water, while the upper end may be closed by a stopper, C. When the air is condensed in the vessel, and the stopper of the tube is opened, the pressure of the air will force up the water in a jet to a height proportional to the pressure.

Fig. 182.



If a horizontal tube, open at each end, and having its extremities bent horizontally in contrary directions, be mounted so as to revolve freely about a vertical axis, and be attached to the vessel used in the preceding experiment, the pressure of the water, as it escapes from the horizontal tube, will cause the tube to revolve with great velocity.

Fig. 183.



317. *The intermitting fountain* consists of a close reservoir, A, nearly filled with water, and having two or three small tubes, B, B, through which the water may escape in a fine stream. CC is a tube, open at both ends, whose upper extremity rises above the level of the water in the reservoir, while the

lower extremity descends nearly to the bottom of the basin D. In the bottom of this basin is a small opening by which the water may escape into the second basin, E. When the lower end of the tube CC is unobstructed, the air enters the tube, and exerts its pressure on the surface of the water in the reservoir A; but when the lower end of the tube is covered by the water which accumulates in the basin D, the air can no longer enter the tube; and as the pressure in the reservoir gradually diminishes from the rarefaction of the air, resulting from the escape of the water through the tubes B, B, the flow from B, B ceases until the end of the tube CC is freed by the escape of the water from the basin D into the basin E, when air again enters the tube, and supplies the reservoir A. Thus, whenever the lower end of the tube CC is covered with water, the flow from B, B is interrupted, and it is resumed as soon as the end of the tube CC becomes free.

There are some natural springs which flow freely for a time, and then cease for a certain interval, after which they flow again.

BOOK FOURTH.

ACOUSTICS.

SECTION I.

THEORY OF WAVES OR UNDULATIONS.

318. *Acoustics is that branch of Natural Philosophy which treats of the nature and laws of sound.*

Sound is the sensation produced in the organs of hearing when they are affected by the undulations of the atmosphere, or any other suitable medium.

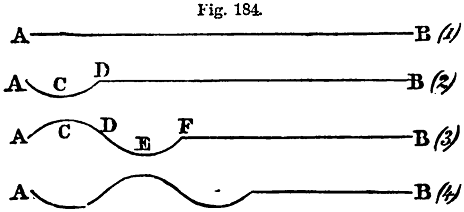
Since undulations are the cause of sound, we will begin with studying their theory.

319. *Theory of waves or undulations.* Waves may be excited in solid, liquid, or gaseous bodies.

I. *Waves in solid bodies.*

Let AB be a flexible and elastic cord, stretched between two fixed points, A and B, and let it receive a transverse blow near the end A. The cord immediately assumes the form ACDB, *Fig.* (2), the part ACD lying below the position of equilibrium of the cord. After a brief instant, the elasticity of the cord brings it back to its mean position, and its inertia carries it to an equal distance on the other side, while the effect of the original blow has now extended to a distance double of AD, and the position of the cord is such as is shown in *Fig.* (3). The elasticity of the cord presently brings it back to its mean position, and its inertia carries the portions ACD, DEF to an equal distance on the other side of their mean position, while the effect of the original blow ex-

Fig. 184.



tends to three times the length of AD, and the position of the cord is such as is shown in *Fig.* (4). The resistance of the air, and the want of perfect elasticity in the cord, soon bring the portions ACD, DEF nearly to rest; but the effect of the original blow extends uniformly along the cord from A to B. *The curve* ACDEF *is called a wave.*

On arriving at the extremity B, the wave returns from B to A in the same manner as it advanced from A to B. It thus travels back and forth, until the motion becomes too slight to be appreciable.

In this case, *the appearance is as if some material body traveled rapidly from one end of the cord to the other; but, in fact, the particles of the cord have only a motion of up and down, or perpendicular to the length of the cord. The wave, therefore, which travels from one end of the cord to the other, is a mere form or outline; that is, a wave is not a progressive moving body, but an advancing form.*

320. II. *Waves in liquid bodies.*

If we drop a pebble into a vessel containing water at rest, a series of circular waves is formed which spread with uniform velocity in all directions from the centre of disturbance. The waves consist of alternate elevations and depressions rapidly succeeding each other. *The appearance is as if the liquid itself was advancing in the direction of the wave,* but this appearance is an illusion. If we observe a piece of wood floating on the waves, we perceive that it is not carried along with them. It is alternately raised and lowered, as the wave elevations and depressions uniformly glide away from under it.

The force by which waves in water are propagated is gravity; for if from any cause an elevation or a depression be produced on the horizontal surface of the water, the gravity of the particles endeavors to restore the disturbed horizontal plane, by which means an oscillatory motion is produced, which is gradually propagated from one particle to another.

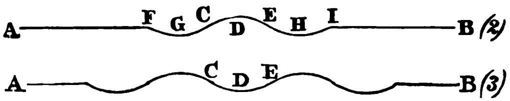
Let ACDEB represent the surface of the water in which a

Fig. 185.

depression, CDE, has been made by the impulse of a pebble. The pressure of the surrounding particles forces the portion CDE

up into the horizontal line AB, but their inertia carries them as far above the line AB, while at the same time the effect of the first impulse extends on each side of CDE, and the surface of the water presents the outline FGCDEHI, as shown in *Fig.* (2).

Fig. 186.



During the next instant, the particles CDE fall back to their former level, and their inertia carries them as much below this level as they were before above it, while the effect of the first impulse extends still farther on each side, presenting the outline represented in *Fig.* (3). Thus is formed a succession of rings of gradually increasing diameters, and the appearance is that of a body of water traveling away from the first point of disturbance. In reality, *the motion of the particles of the water is simply up and down*, while *that which appears to be moving off in a horizontal direction, is merely a form or outline.*

321. When two waves which proceed from different centres encounter each other, they may modify each other in a remarkable manner.

If the elevation of one wave coincides with the elevation of another, and the depressions also coincide, a wave will be produced whose elevation is equal to the sum of the elevations of the two waves, and the depth of its depression will be equal to the sum of the depressions of the two waves. If the heights and depressions of the two waves are equal, *the resulting wave will have a double elevation and a double depression.* If the elevation of one wave coincides with the depression of the other, the result will be a wave whose elevation will be equal to the difference of the elevations of the two superposed waves, and its depression will be equal to the difference of their depressions. If the heights of the two waves are equal, *the two will mutually destroy each other*, and there will be neither elevation nor depression at the point in question.

This phenomenon, in which the depression of each wave is filled up by the elevation of the other, is called *an interference of waves.*

322. III. *Waves in gaseous bodies.*

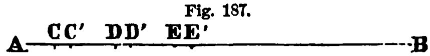
Suppose a sphere of air, having a diameter of one inch, to be suddenly compressed into a sphere of half an inch in diameter. As soon as it is relieved from the compressing force, the air, in consequence of its elasticity, will expand to its former dimensions, and its inertia will cause it to swell into a sphere exceeding its former volume. After this, the pressure of the surrounding air will cause it to contract; it will then expand again as at first, thus forming alternately spheres with diameters less and greater than an inch, until at length the oscillation ceases.

These oscillations will not be confined to the sphere of air in which they commenced. The surrounding air will follow the contracting sphere when first compressed, so that a spherical shell of air on the outside of the sphere will expand, and become *less dense* than in its state of repose.

When the central sphere expands, the external spherical shell will contract, and will become *more dense* than in its state of repose. This shell will act in a similar manner upon another spherical shell outside of it, and this upon a third, and so on. Thus we shall have a series of spherical shells of air, alternately condensed and expanded in a greater degree than when in a state of repose.

323. Let us examine more carefully what takes place in a series of particles of air extending in a straight line from the centre of disturbance, A, toward B. Imagine the air to be suddenly pressed from A to C by a solid surface moving against it. Since air is perfectly elastic, it will yield to the force exerted upon it, and during the motion from A to C the compression will extend to a certain distance beyond C. Let this distance be CE. All the particles between C and E will be more or less compressed, but not equally so. The compression will be greatest at D, midway between C and E, and will be less and less toward C and E.

Fig. 187.



The arrangement of the particles of air between C *and* E *is called a wave or undulation, and the distance* CE *is called the length of the wave.*

At the next moment of time after the arrival of the compress-

ing surface at C, the state of unequal compression just described as prevailing between C and E will prevail between C′ and E′, and the point of greatest compression will have advanced to D′; that is, *this state of unequal compression will advance uniformly toward* B.

324. If we suppose the solid surface which causes the compression to be at C, and to move suddenly from C to A, the air which was contiguous to it on the right of C will rush after it in consequence of its elasticity, so that the air to the right of C will be rendered *less dense* than previously. A change will thus be made upon the air between C and E exactly the reverse of that which was previously made; that is, the rarefaction will be greatest at the middle point D, and it will gradually diminish from D toward C and E. This state of unequal rarefaction will advance uniformly toward B, but the centre D, instead of being a point of greatest condensation, will be a point of greatest rarefaction.

The arrangement of the particles of air between C *and* E *is also in this case called a wave*, but *the former is called a condensed wave*, and *the latter a rarefied wave.*

325. If now *the compressing surface moves alternately backward and forward between* A *and* C, the two series of waves will be produced in succession. While the condensed wave moves from A toward B, the rarefied wave will immediately follow it; this rarefied wave will be followed by another condensed wave, and so on.

What has been said of a single line of particles extending from A in a particular direction, is equally true of every line diverging from A; and hence the succession of condensed and rarefied waves will be propagated from the centre, and *each wave will form a spherical surface* continually expanding.

326. If two series of waves coincide as to their points of greatest and least condensation, a series will be formed whose greatest condensation and rarefaction is equal to *the sum of the separate series;* and if the points of greatest condensation of the one coincide with the greatest rarefaction of the other, the series will have condensations and rarefactions equal to *the difference of the separate series;* and if the condensations and rarefactions are equal, the waves will efface each other; that is, we shall have

an interference of undulations. These interferences may be exhibited experimentally, as will be shown in Art. 339.

SECTION II.

PRODUCTION AND PROPAGATION OF SOUND.

327. The atmospheric undulations which produce the sensation of sound, are usually excited by the vibration of elastic bodies. These vibrations are frequently imparted to other bodies susceptible of vibration, by which they are finally communicated to the air, and thence to the organ of hearing.

The vibrating bodies which thus impart undulations to the air are called sounding bodies.

Vibrations in the sounding body are the cause of sound. Thus, when sound is emitted by the string of a violin, or by a bell-glass, or by a tuning-fork, the vibration is visible to the eye, or may be rendered evident by some artifice.

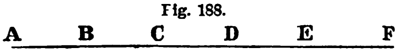
That the presence of air or other conducting medium is necessary for the transmission of sound, is proved by ringing a bell under the exhausted receiver of an air-pump, where no sound is heard, although the vibrations of the bell are distinctly visible.

On the summit of lofty mountains, where the air is highly rarefied, sounds are greatly diminished in intensity. On the summit of Mont Blanc, the report of a pistol is no louder than a common cracker.

Hence we conclude that no sound can reach us from any body beyond the earth's atmosphere.

Persons confined in a close room are sensible of sounds produced at a distance outside of the room. In this case, the undulations of the external air produce vibrations in the windows and walls, and these produce corresponding vibrations in the air within the room, by which the organs of hearing are affected.

Fig. 188.



328. *Sound requires time for its propagation.* Let a series of observers, B, C, D, etc., be placed in a straight line at a distance of 1100 feet from each other, and let a pistol be fired at A, 1100 feet from

B. The observer B will hear the report of the pistol one second after he sees the flash, the observer C will hear the report two seconds after the flash, the observer D will hear the report three seconds after the flash, and so on with the other observers; from which we infer that *sound passes through the air, not instantaneously, but progressively, and at a uniform rate.*

In 1822, very accurate experiments were made near Paris to determine the velocity of sound. The sounding bodies employed were pieces of artillery, distant nearly twelve miles, and they were charged with from two to three pounds of powder. The experiments were made at midnight, in order that the flash might be more easily noticed, and to obtain a more tranquil atmosphere. The result of these experiments was that, *with the thermometer at* 32°, *the velocity of sound is* 1086 *feet per second,* and *the velocity increases* 1.12 *feet per second for every degree that the thermometer rises.*

329. *All sounds, whatever be their pitch or intensity, travel with the same velocity.* This is proved by the absence of all confusion in the effects of music, at whatever distance it may be heard. If the different notes simultaneously produced by the various instruments of an orchestra, traveled through the air with different velocities, they would be heard by a distant person at different moments, which would produce intolerable confusion.

Knowing the velocity of sound, we can compute *the distance of a sounding body* by comparing the moment at which the sound is produced with the moment at which it is heard. When sound is attended with the evolution of light, as in the case of fire-arms, and of atmospheric electricity, the flash may be seen the instant the sound is produced. In these cases, the distance may be ascertained by multiplying the number of feet per second in the velocity of sound, by the number of seconds in the interval between the flash and the report. Thus, if the flash of a cannon be seen ten seconds before the report is heard, and the temperature be such that the velocity of sound is 1120 feet per second, the distance of the cannon must be 11,200 feet.

Example. A gun having been fired at Fort Lee, the sound was heard by an observer near New York, 45 seconds after seeing the flash, the temperature of the air being 72°. Required the distance of the observer from the fort.

Ans. 50886 feet, or 9.63 miles.

330. *Liquids are also capable of propagating sound.* Two stones struck together at the bottom of a river produce a sound which is audible at a great distance. Sounds are transmitted through water with greater force than through air. A blow struck by a hammer upon a bell under the water of the Lake of Geneva was distinctly heard across the lake, a distance of nine miles. *The velocity of sound in water is* 4708 *feet per second.*

331. *Solids which possess elasticity have likewise the power of propagating sound.* If the end of a beam be scratched with a pin, the sound may be heard by an ear placed at the other end, although the same sound may not be audible to the person who produces it.

The earth itself conducts sound. By putting the ear to the ground, the approach of a troop of horse can be heard at a great distance, and the approach of a distant railway train can be ascertained by applying the ear to the rail. *The velocity of sound through glass and steel is sixteen times its velocity through air;* and *its velocity through most kinds of wood is from* 10 *to* 16 *times its velocity in air.*

332. *Reflection of waves.*

If a series of waves impinge against any smooth and hard surface, they will be reflected, and will return as if they emanated from a centre equally distant on the other side of the obstructing surface. Hence it follows that the same law prevails in the reflection of waves as when a perfectly elastic ball impinges upon a smooth surface, viz., *the angle of reflection is equal to the angle of incidence.*

Since lines drawn from any point of an ellipse to the two foci make equal angles with the tangent, it follows that, *if a series of waves be propagated from one focus of an ellipsoidal surface, they will be reflected to the other focus.*

So, also, if a series of waves diverge from the focus of a parabola, these waves, after striking the surface, will be reflected so as to form a series of waves parallel to the axis of the parabola; or, if a series of waves strike a parabolic surface moving parallel to the axis of the parabola, they will be reflected toward the focus of the parabola.

333. *These principles explain the production of echoes.*

When a sound is heard by means of undulations proceeding directly from the sounding body to the ear, and afterward by

undulations returned to the ear from some reflecting surface, *this repetition of the sound is called an echo.* To produce an echo, it is necessary, therefore, that there should be a reflecting surface of sufficient magnitude, and suitably placed with respect to the ear.

If a person stand midway between two parallel walls, A and B, they will reflect to his ear the sound of his own voice, producing an echo. Moreover, a part of the wave reflected from B will proceed to A, and, being reflected from A, will arrive at C, producing a second echo. The interval between the two echoes will be the time which sound requires to move over the distance between the two walls. If the two walls, A and B, are distant from each other 112 feet, the interval between the first sound and its echo will be one tenth of a second; and the same interval will take place between the successive echoes. If the observer stand at a point C, nearer to A than B, the echo proceeding from the reflection by the wall A will be heard before the echo proceeding from the wall B; that is, one reflection from each of the two walls will produce two echoes. So, also, a second reflection from the two walls will produce two more echoes, and so on indefinitely. Each reflected wave is, however, more feeble than the preceding, so that the waves soon become too feeble to affect the ear.

Fig. 189.

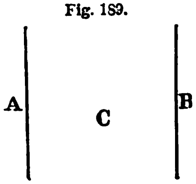
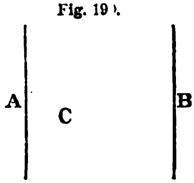


Fig. 190.



334. If a reflecting surface be distant 1120 feet, an echo will be perceived at the end of two seconds. Now a speaker can articulate distinctly four syllables in a second; that is, *a reflecting surface, distant* 1120 *feet, will return an echo of eight syllables.* If the speaker attempt to utter more than eight syllables, the first syllable of the echo will blend with the ninth syllable of the speaker, and produce confusion. The more distant the reflecting surface, the greater will be the number of syllables returned to the speaker; but when the distance is too great, the reflected waves become too feeble to affect the ear. There are several remarkable localities where the echo repeats distinctly twelve

or fifteen syllables. Near Oxford, England, is an echo which repeats seventeen syllables by day, and twenty by night. The reflecting surface is distant 2280 feet. One of the most remarkable echoes in the neighborhood of New York is under the arches of the High Bridge at Harlem.

335. If a sounding body be placed in one focus of an ellipsoid, the ear being at the other focus, the sound will be first heard from undulations proceeding directly from one focus to the other; and it will be afterward heard by waves which strike upon the elliptic surface, and are reflected to the other focus. It is not necessary that the elliptic surface be complete. A small portion of an elliptic surface will reflect sound in the same manner as the entire ellipse, but the force of the echo will correspond to the magnitude of the reflecting surface. If we place a watch in one focus of a concave elliptical mirror, the ticking may be heard in the other focus, although distant 40 or 50 feet.

If a person stand in the centre of a sphere bounded either wholly or in part by smooth reflecting surfaces, he will hear the echo of his own voice, and the echo will reach his ear after an interval equal to that which sound requires to move over the diameter of the sphere. If he be surrounded by portions of two or more spheres, of which he is the common centre, he will hear a succession of echoes of his own voice. Near Franconia, New Hampshire, is a small lake called Echo Lake. When a cannon is fired on the shore of the lake, a startling echo is returned from a succession of cliffs at different distances, presenting a strong resemblance to the reverberation of thunder. Similar echoes abound among the Alps in Switzerland.

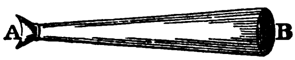
336. *Whispering galleries* are formed by smooth walls having a continuous curved form. Both speaker and hearer must be near the wall, but they may be on opposite sides of the gallery. In this case, the sound is reflected successively from one point of the wall to another, until it reaches the observer's ear. At the base of the dome of St. Paul's Cathedral, in London, is a cylindrical gallery of this description.

337. *Speaking tubes* are long tubes of small diameter, which confine the waves proceeding from the mouth at one end of the tube, and prevent them from being scattered through the surrounding atmosphere, so that they proceed to a great distance

with but little loss of force. They are, therefore, very useful in large buildings, where many persons are employed.

The speaking trumpet is an instrument of such a form that the waves which diverge from the mouth of the speaker at A, are reflected in directions parallel to the axis of the instrument, A, B. The waves, therefore, which reach an ear situated in the direction of this axis, will have much greater intensity than would the diverging waves which proceed from a speaker without such instrument.

Fig. 191.



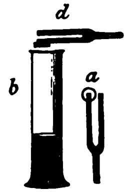
The hearing trumpet is in principle the same as the speaking trumpet. The waves of sound, proceeding from a distant speaker, enter this instrument at the larger end, and are so reflected as to become united at the smaller end, which is applied to the ear.

338. *Interference of sounds.*

Two series of sonorous undulations may be made to interfere with each other; that is, *two loud sounds may be made to produce silence.* Suppose we have two tuning forks, one of which makes 100 vibrations per second, and the other 101, and suppose them to commence their vibrations together; then, at the first vibration, the two forks will produce one sound of double the strength of either; but the one fork will gradually gain upon the other, till at the 50th vibration it has gained half of one vibration on the other. The two forks now tend to impress contrary motions upon the air at the same time; the undulations, therefore, interfere and destroy each other, and an interval of silence takes place. The sound will presently recommence, and gradually increase till the 100th vibration, when the two conspire to produce a sound of double the strength of either. An interval of silence will again occur at the 150th, 250th, etc., vibration, while a sound of double the strength of either will be heard at the 200th and 300th vibration; that is, the doubled sound and the period of silence succeed each other at intervals of one second. *If the one fork gains upon the other four vibrations per second, four of these interferences will occur in a second, producing a succession of swells or beats.* If one fork makes 8 or 10 vibrations per second more than the other, the succession of beats is so rapid as to resemble a rattle.

339. In order to exhibit these results, take two tuning forks, *a* and *d*, of the same note, and attach to one of the prongs of each, a circle of card paper half an inch in diameter, and make one of the forks a little heavier than the other by loading it with wax. Then filling a jar, *b*, with water to such a height that either of the forks, when held over it, will make it resound, so long as only one is held over the jar, there will be a continued note without interruption; but if both are held over the jar together, *there will be periods of silence and periods of sound, producing a succession of swells or beats.*

Fig. 192.



If, with an organ, we open simultaneously two keys differing by a semi-tone, these beats are exhibited with great force, producing the sounds *wow—wow—wow.*

When a heavy bell is struck with a hammer, we frequently hear a succession of swells. The bell consists of a series of rings, of diameters somewhat unequal, and tending, therefore, to vibrate in unequal times. When all these vibrations conspire, they produce a sound of unusual intensity; but when they are opposed to each other, they produce a note of diminished intensity.

SECTION III.

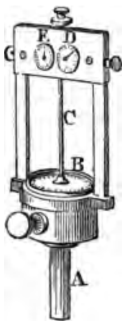
MUSICAL SOUNDS.

340. *Musical sounds are caused by vibrations recurring at very short and equal intervals.* If the vibrations succeed each other very slowly, they produce upon the ear the impression of distinct and successive sounds. This may be shown by vibrating a thin plate of steel of considerable length. If the vibrations be repeated at least 32 times per second, the sound appears continuous, and is called musical. In some rare cases, when the vibrations succeed each other at the rate of only 8 per second, the sound becomes continuous, and forms an exceedingly grave musical note. As the vibrations become more rapid, the note rises in pitch; and the vibrations may succeed each other so rapidly as to be incapable of affecting the ear. The sensibility of the ear for musical sounds ceases at about 24,000 vibrations per

second. *The entire range of musical sounds, therefore, extends from* 8 *to* 24,000 *vibrations per second;* or, the most rapid vibration is 3000 times the least.

341. *The number of vibrations corresponding to any musical note may be determined by means of an instrument called the acoustic syren.* This consists of a tube, A, an inch or more in diameter, through which air may be impelled by means of a bellows or the mouth. This tube is closed by a circular plate, perforated by 16 small holes, made near together, and disposed in the form of a circle; the perforations being made, not perpendicularly to the plate, but obliquely through it. Upon this plate is fixed another plate, B, of the same size, and having a circle of similar holes, but inclined in a direction contrary to the former, and this plate is capable of revolving round its axis with very little friction. When this plate revolves, the holes in the upper plate correspond in certain positions with the holes in the lower plate; and if air be impelled through the tube, it will flow through both plates; but in intermediate positions, since the holes in the two plates do not correspond with each other, the flow of air from the tube is stopped. Since the holes in the upper plate are made oblique to its axis, the mere impulse of the air against the sides of the holes is sufficient to give a rapid rotation to the plate. When the upper plate revolves with a uniform velocity, a series of puffs of air will escape from the holes of the plate, with equal intervals of time between them; and when the velocity is sufficiently great, the undulations thus excited will produce a musical note. *By varying the force of the current of air, we may vary the velocity of rotation of the upper plate, and produce a sound of any desired pitch, either grave or acute.*

Fig. 193.



342. The number of undulations produced, is registered in the following manner. To the upper plate is attached a spindle, C, which carries an endless screw, which drives the teeth of a small wheel, which is connected by a pinion with a second wheel. These wheels govern the motion of hands, D and E, moving upon small dials which indicate the number of undulations. If, at the commencement of an experiment, these hands

stand at their respective zeros, their position at the end of any known interval of time will indicate the number of undulations produced in this interval, and will therefore determine the number of vibrations per second corresponding to the note produced.

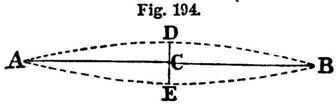
343. *Musical sounds may differ from each other in three particulars—in intensity, pitch, and quality.* The intensity of a sound, or its degree of loudness, depends upon *the extent of the oscillations* of the vibrating body, or upon the degree of condensation produced at the middle of the sonorous wave.

The pitch of a musical note may be either grave or acute, and *depends on the frequency of the vibrations.* The more rapid the vibrations, the more acute will be the sound.

The quality of a musical sound depends upon circumstances not fully understood. Different musical instruments, as, for example, a flute and a violin, may produce notes of the same pitch and intensity, yet the ear readily distinguishes the one instrument from the other. The quality of a note appears to depend in some way upon *the nature of the vibrating body.*

344. *Vibrations of an elastic string.* If an elastic string be stretched between two fixed points, and be drawn laterally from its position of rest, as soon as it is left to itself, its elasticity will bring it back to the position of rest, but its inertia will carry it to an equal distance on the other side; its elasticity and inertia will bring it back again to the first position, and thus it will vibrate to and fro for a long time. Let AB be an elastic string, stretched between the two points A and B by a force much greater than its own weight. If it be drawn aside

Fig. 194.



from its position of rest into the position ADB, and be then left to itself, its elasticity will bring it back to the position ACB, but its inertia will carry it beyond this line into the position AEB. Its elasticity will again bring it back to the position ACB, but its inertia will carry it again into the position ADB; and thus it will vibrate back and forth like a pendulum. *The motion of the string from the point* D *back to the same point again, is called a double vibration.*

The force which impels the point D toward the line AB increases as the distance from the line AB increases. The great-

er the excursion which the string makes from the position of rest, the greater will be the force which brings it back; and consequently the time of vibration will continue the same, whether the extent of the vibration be large or small; that is, *the time of vibration is independent of the amplitude of the vibrations.*

345. The following are the laws which govern the vibrations of musical strings.

I. *The number of vibrations per second is inversely proportional to the length of the string.* One half the length of a musical string makes twice as many vibrations per second as the entire string.

II. *The number of vibrations per second varies as the square root of the weight by which the string is stretched.* In order that the number of vibrations per second may be doubled, the weight by which the string is stretched must be quadrupled.

III. *The number of vibrations per second varies inversely as the square root of the weight of a given length of the string.* If one string be four times as heavy as another of the same length and tension, it will make only half as many vibrations per second.

346. If we put

L = the length of the string in inches,
W = the weight of one inch of the string,
T = the weight by which the string is stretched,
N = the number of double vibrations made per second,

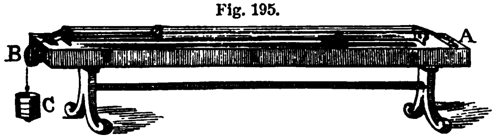
then $N = \frac{1}{L}\sqrt{\frac{193\ T}{2\ W}}$.

Example. How many vibrations per second are made by a string 11 inches long, of which one inch weighs $\frac{3}{4}$ of a grain, when the weight of tension is 25 pounds, or 175,000 grains?

Ans. 431 double vibrations.

These laws may be verified by means of the acoustic syren and the monochord. The *monochord* consists of a string of catgut or wire, one end of which is attached to a fixed point, A, while the other is carried over a pulley, B, and is stretched by a heavy weight, C.

Fig. 195.



Under the string is a sounding board, to the frame of which the pulley is attached.

347. When a musical string vibrates throughout its entire length, and all the parts move in the same direction, the note produced is called *the fundamental note.*

All civilized nations have agreed in adopting as the foundation of their music a particular succession of sounds, called *the diatonic scale.* The lengths of a given string required to sound the eight notes of the scale are,

$$1, \tfrac{8}{9}, \tfrac{4}{5}, \tfrac{3}{4}, \tfrac{2}{3}, \tfrac{3}{5}, \tfrac{8}{15}, \tfrac{1}{2}.$$

These notes are generally distinguished by the letters A, B, C, D, E, F, G, A. The last note, or that corresponding to a vibration of one half the whole string, is *the octave* of the fundamental note. The lengths of the same string required to sound the eight notes of the second octave are,

$$\tfrac{1}{2}, \tfrac{4}{9}, \tfrac{2}{5}, \tfrac{3}{8}, \tfrac{1}{3}, \tfrac{3}{10}, \tfrac{4}{15}, \tfrac{1}{4}.$$

348. The number of vibrations per second varies inversely as the length of the string. Hence the number of vibrations per second corresponding to the fundamental note, is one half of that corresponding to its octave.

The number of vibrations per second corresponding to each note of the musical scale, will be proportional to the reciprocals of the preceding numbers, or

$$\begin{array}{cccccccc} 1, & \tfrac{9}{8}, & \tfrac{5}{4}, & \tfrac{4}{3}, & \tfrac{3}{2}, & \tfrac{5}{3}, & \tfrac{15}{8}, & 2, \\ \mathrm{A} & \mathrm{B} & \mathrm{C} & \mathrm{D} & \mathrm{E} & \mathrm{F} & \mathrm{G} & \mathrm{A}. \end{array}$$

349. If we compare these numbers with the effect produced on the ear by the combination of the corresponding notes, we shall discover *the cause of the sensation of harmony and of discord.*

The most perfect harmony is that of the octave. Now two vibrations of the octave are made in the same time as one of the fundamental note; that is, *the commencement of each alternate vibration of the octave, coincides with the commencement of a vibration of the fundamental note.*

Next to the octave, the most agreeable harmony is that of the fifth, which is produced when the fundamental note, A, is sounded simultaneously with E. Now three vibrations of E are made in the same time as two of A; that is, *every third vibration of* E *commences simultaneously with every second vibration of* A. The coincidences are therefore twice as frequent in the octave as in the fifth.

Next to the fifth, the most agreeable harmony is the fourth,

which is produced when the fundamental note A is sounded simultaneously with D. Now four vibrations of D are made in the same time as three of A, and therefore *there is a coincidence at the commencement of every third vibration of the fundamental note.*

The harmony which comes next in order to the fourth is that of the third, produced when the fundamental note is sounded simultaneously with C. Now five vibrations of C are made in the same time as four of A, and therefore *there is a coincidence at every fourth vibration of the fundamental note.* Thus we see that *musical chords are characterized by a frequent coincidence of vibrations,* while *discords are characterized by a rare coincidence of vibrations.*

350. When a string is made to sound its fundamental note, a practiced ear will often detect *its several harmonics* mingled with it. Thus the first and second octaves are easily produced, but these are so nearly in unison with the fundamental note, that it is more difficult to distinguish them. The twelfth, or that which has three vibrations for one of the fundamental note, is easily perceived; and a practiced ear can often distinguish the seventeenth, or that which has five vibrations for one of the fundamental note.

These phenomena may be exhibited with the monochord. When the string is put into vibration, it exhibits subordinate vibrations, which take place in its aliquot parts. If we place a bridge at the middle of the string, and vibrate one half of the string with a bow, *the other half will immediately vibrate in unison with it.*

Fig. 196.

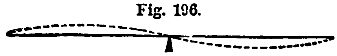
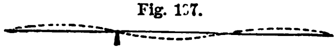


Fig. 197.



If we place the bridge at the end of one third of the string, *the remaining two thirds will be put in vibration as a whole; or it will divide itself into two parts, each vibrating in unison with the first third;* or both of these modes of vibration may take place simultaneously. If we place the bridge at the end of one fourth of the string, the remaining three fourths will divide itself into three parts, each vibrating in unison with the first fourth; or the three fourths may vibrate as a whole. Hence we see that a vibrating cord may have any number of points of rest, separated by equal vibrating portions which lie alternately above and below the axis. Such *points of*

rest are called nodes, and the intermediate vibrating portions are called ventral segments.

351. Each of the preceding modes of vibration has its appropriate note, which is readily distinguished by the ear. If now we remove the bridge, and apply the bow near to one end of the string, it is possible, by a skillful management of the bow, to produce *all of these notes at the same instant.* Thus, while a string is sounding its fundamental note, a practiced ear may detect, at the same time, its fifth, its octave, its twelfth, its fifteenth, and sometimes still other harmonics, showing that all these different modes of vibration take place simultaneously.

352. *Number of vibrations corresponding to any musical note.* By accurate experiments made with the syren, it has been found that *the lower* A *of the treble clef is produced by imparting undulations to the air at the rate of about* 880 *single vibrations, or* 440 *double vibrations per second.* By single vibrations is to be understood condensed waves only, or rarefied waves only; and a double vibration is the combination of a condensed and rarefied wave. It is more common to take the double vibration as the unit. The pitch of the note A is not identically the same in all orchestras. At the Academy of Music at Paris, this note corresponds to 431 vibrations per second.

353. The absolute number of vibrations corresponding to each note of the musical scale may be computed, by combining this result with the relative number of vibrations before given. We shall find them to be as follows:

A	B	C	D	E	F	G	A	B	C	D
440	495	528	594	660	704	792	880	990	1056	1188, etc.

354. *Length of sonorous waves.* By combining the velocity of sound with the rate of undulation, we may determine the length of the sonorous waves corresponding to any given note. Thus, if 440 undulations of the note A strike the ear in a second, and the velocity of sound is 1120 feet per second, we conclude that in 1120 feet there are 440 undulations; that is, the length of each undulation is about $2\frac{1}{2}$ feet. In the same manner we may determine the length of the sonorous waves corresponding to any musical sound.

To find the length of the waves corresponding to the gravest possible note, we must divide 1120 by 8, and we obtain 140 feet.

To find the length of the waves corresponding to the highest possible note, we must divide 1120 by 24000, and we obtain one half inch.

The gravest note employed in music is that corresponding to $17\frac{1}{2}$ *vibrations per second, in which the length of the wave is* 64 *feet.*

The highest note employed in music is that corresponding to 4480 *vibrations per second, in which the length of the wave is* 3 *inches.*

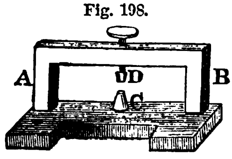
355. *Sonorous undulations may be produced by air acting upon air.* All wind instruments are examples of this principle. The air by which the undulations are produced, may proceed either from a bellows or from the lungs. The pitch of the sound produced depends on the length of the tube. *The gravest note which a tube is capable of producing is that corresponding to an undulation of its own length.* By skillfully managing the action of the air upon entering the tube, the harmonics of the fundamental note may be produced. When these harmonics are produced, nodal points will be formed in the column of air included in the tube; and if the tube were divided at these nodal points, the removal of a part of the tube would not alter the pitch of the note produced.

In many wind instruments, various notes are produced by opening and closing holes in their sides by means of the fingers or keys. When we open a hole in the side of a tube, we virtually change the length of the sounding part of the tube, which determines the pitch of the note produced.

356. *Vibrations of thin plates.*

In order to examine the vibrations of thin plates, we provide a frame, AB, having a small cylindrical piece of cork, C, secured to its base, and another piece of cork, D, attached to a screw, by which it may be brought into contact with the former, so as to press firmly between them an interposed plate.

Fig. 198.



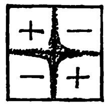
An elastic plate being inserted between the two supports, it is put in vibration by means of a violin bow drawn across its edge.

To ascertain the state of vibration of the surface of the plate, we cover it with a fine black sand, to which motion is imparted by the vibrating surface. Those portions which are at rest, impart no motion to the sand lying upon them, while the sand

which is upon the vibrating parts is jostled aside until it reaches the lines of repose. *The position of the grains of sand will therefore indicate the lines of repose, which are called nodal lines.*

357. *The gravest note which can be obtained from a square plate* is furnished when it has two nodal lines parallel to the sides of the square, and dividing the plate into four equal parts. The motions of two adjacent parts are always contrary to each other: those marked + making their excursions on one side of the plane of repose, while those marked — are on the other.

Fig. 199.



The next gravest note is furnished when the two nodal lines are diagonals of the square; and *this note is the fifth of the preceding. These two systems of nodal lines may coexist.*

Fig. 200.

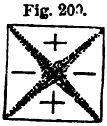
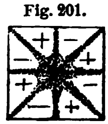


Fig. 201.



An oblong rectangular plate may vibrate so as to have a straight nodal line through the centre, and a curved line near each end. An equilateral triangle may vibrate so as to exhibit three nodal lines, each being drawn from one of the angles to the middle of the opposite side.

Fig. 202.

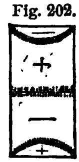
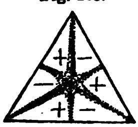


Fig. 203.



A circle may exhibit two nodal lines at right angles to each other. An ellipse may exhibit one nodal line coinciding with its minor axis, and a curved line near each extremity of the major axis.

Fig. 204.

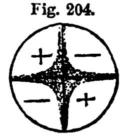
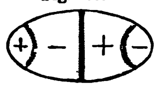


Fig. 205.



The preceding modes of vibration are among *the simplest* of which these plates are susceptible. The nodal lines may exhibit *an immense variety of complicated and curious forms*, especially if the plates be quite thin.

358. *A bell* may be regarded as composed of an assemblage of rings, and *exhibits nodal lines parallel to the axis of the bell.* The gravest note is produced by a division into *four vibrating segments.* The number of nodal lines may be either 4, 6, 8, 10, etc., but *must always be an even number;* and the corresponding number of vibrations will be represented by *the squares of these numbers.* Thus the successive notes of a bell will be represented by

$$4^2, \quad 6^2, \quad 8^2, \quad 10^2,$$

or $$1, \frac{36}{16}, \frac{64}{16}, \frac{100}{16},$$
which are as the numbers
$$1, \frac{9}{4}, 4, \frac{25}{4}.$$

The second note is the ninth of the fundamental sound, and *the third is the double octave.*

To render these vibrations visible, fill a cylindrical glass vessel partly with water, and draw a bow across the edge. The surface of the water will receive an undulatory motion, and when the gravest note is produced, four vibrating segments will be seen on the surface of the water. When the second note is produced, six vibrating segments will be seen, etc.

These different modes of vibration may coincide, as is frequently perceived when a bell is struck with a hammer.

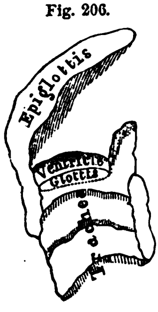
SECTION IV.

ORGANS OF VOICE AND HEARING.

359. *Organ of voice.*

The organ of voice in man consists of a pipe extending through the throat, connected with the lungs at its lower end, and having a complicated apparatus at its upper extremity. This pipe, which is called *the trachea*, consists of several strong cartilaginous rings, united to each other by a flexible membrane. Toward the upper extremity, the trachea is gradually flattened so as to terminate in a narrow opening, about an inch and a quarter in length, called *the glottis*, which is closed by two membranes, called *the chordæ vocales*, capable of being brought into contact or opened at will. Immediately above the glottis is a cavity, called *the ventricle*, about half an inch in height. The upper part of this cavity is provided with an opening, forming a sort of *superior glottis.*

Fig. 206.



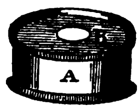
The air, expelled from the lungs through the trachea, passing rapidly through the glottis into the ventricle, and again through the superior glottis, produces sonorous undulations. This sound is modified by the tongue acting on the palate, the mouth, and

the teeth; also by the lips acting on each other, and by the nasal passages.

360. Since with a tube of given length we can obtain only a single note, or its harmonics, it has been considered mysterious how *the human voice is capable of producing every variety of note, from the gravest to the most acute.*

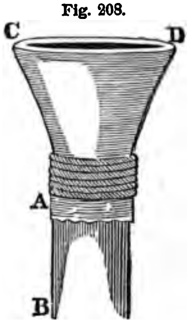
The organ of voice is by some regarded as similar to a whistle known by the name of the bird-call. The ventricle immediately above the glottis is considered analogous to the barrel, A, of the bird-call, while the glottis and the opening above it represent the two holes, B, in the sides of the bird-call. The sonorous undulations are supposed to be imparted to the air by the alternate compression and expansion of the air included in the ventricle. This alternate compression and expansion is varied by the pressure of the air expelled from the lungs.

Fig. 207.



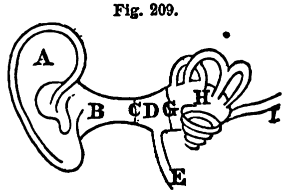
361. It seems, however, more probable that notes are produced in the larynx by *the vibrations of the chordæ vocales*, by which the glottis is alternately closed and opened. The following contrivance is designed to illustrate the action of the glottis. Take a short tube, AB, about half an inch in diameter, and fit to it a cylinder of flexible India-rubber, so as to project about half an inch beyond the tube. If now we flatten the end of the India rubber cylinder, CD, by pulling upon its opposite sides, and then blow through the tube, the India-rubber will be put into vibration, and *we shall obtain a series of notes whose pitch depends upon the tension of the rubber and the force of the current of the air.*

Fig. 208.



362. *The organ of hearing* in man consists of three distinct parts. The first, A, is analogous to the ear-trumpet, and serves to collect the waves of sound, and reflect them inward into a pipe, B, which gradually contracts, and terminates in a small aperture covered by a membrane, C, tightly stretched over

Fig. 209.



it. This membrane, called the *membrana tympani*, vibrates in sympathy with the undulations of the air.

Behind this membrane is the second chamber of the ear, D, called *the drum*, filled with air by a pipe, E, communicating with the mouth. At the inner extremity of the second chamber is another opening, called *the fenestra ovalis*, covered by a similar elastic membrane, G. Within this opening is the inner ear, H, filled with a complicated mechanism of canals and ducts. This inner chamber is filled with a liquid, in which floats the acoustic nerve, consisting of a bundle of fine cords. This nerve, I, is continued to the brain.

The undulations of the external atmosphere collected by the external ear, impart corresponding vibrations to the membrana tympani, by which the vibrations are transmitted to the air which fills the cavity within the tympanum. These undulations are next imparted to the membrane which is stretched over the fenestra ovalis. The vibrations of this membrane are imparted to the liquid which fills the inner ear, and which contains the acoustic nerve. This nerve receives the vibrations from the fluid around it, and transmits them to the brain.

BOOK FIFTH.

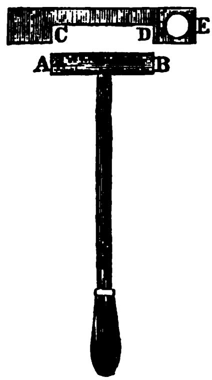
HEAT.

SECTION I.

EXPANSION—THERMOMETERS.

363. *All bodies, whether solid, liquid, or gaseous, are expanded in their dimensions by an increase of heat.*

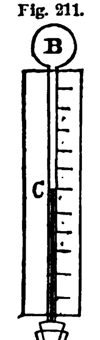
Fig. 210.



If we take a cylindrical rod of iron, AB, of such length that at the common temperature it may just pass between two fixed points, CD, and its diameter be such that it will just pass through a round hole, E; when the iron is heated, it will be too long to pass in one direction, and too thick to pass in the other. After being cooled, it will again pass as at first.

If a glass bulb, to which a small tube is attached, be filled with a liquid, when it is heated the liquid will ascend in the tube.

Fig. 211.



Take a long tube, AB, having a glass bulb, B, blown at one end, the other end being open, and plunged into a glass vessel containing a colored liquid. When the bulb is heated, a portion of the air will be expelled; when the temperature falls, the air will contract, and the liquid rise in the tube.

The magnitude of objects depends, therefore, upon their temperature. A scale which is a yard long in summer, is less than a yard in winter. A vessel which holds a gallon in winter, will hold more than a gallon in summer.

364. *Measures of temperature.* The expansion of a body may therefore be employed to measure the degree

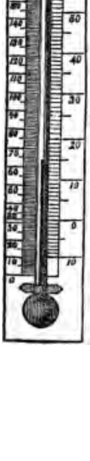
of its heat. The degree of heat we term *temperature;* and the instruments by which the temperature of bodies is indicated are called *thermometers.*

Thermometers may be formed of solid, liquid, or gaseous bodies. The substance most generally employed for thermometers is *mercury.* The mercurial thermometer consists of a capillary glass tube, at one end of which is a small and thin bulb, the bulb and a part of the tube being filled with mercury.

Glass and mercury are both expanded by an increase of heat. If both substances expanded *equally,* the column of mercury in the tube would neither rise nor fall with a change of temperature, since the increase of volume of the mercury would be exactly equal to the increase of the capacity of the bulb. The expansion of mercury is, however, *twenty times* that of glass; and therefore, if the bulb be warmed, the mercury will rise in the tube; if the bulb be cooled, the mercury will sink in the tube.

365. *Thermometric scale.* In order that the thermometer may afford a numerical measure of temperature, a scale must be attached to the tube, and two standard temperatures must be selected, to which the mercury can be reduced when a thermometer is required to be constructed or verified.

Fig. 212.



The standard temperatures universally employed for this purpose are *melting ice* and *boiling water.* The former is called the *freezing point,* and the latter *the boiling point.*

In Fahrenheit's thermometer, the former point is marked 32, and the latter 212, the interval being divided into 180 equal parts. The same divisions are continued upon the scale, above and below the two standard points. This scale was adopted about 1720. The zero of the scale was fixed at 32° below the freezing point, because this was the most intense cold which Fahrenheit was able to obtain by a freezing mixture, and was believed to be the greatest degree of cold which could occur in nature.

The divisions of this scale are continued below zero, and degrees below zero are distinguished by the negative sign. Thus +32° signifies 32° above zero; but —32° signifies 32° below zero.

Upon the *centigrade thermometer*, the freezing point is marked 0, and the boiling point 100.

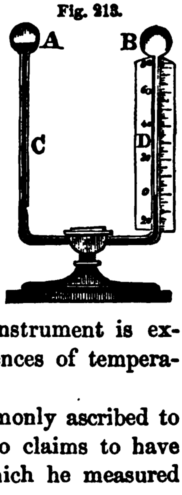
Upon *Reaumur's thermometer*, the freezing point is marked 0, and the boiling point 80.

366. As mercury congeals at —39°, some other substance must be employed for indicating temperatures lower than this degree. For this purpose we generally employ alcohol, a liquid which has never yet been frozen.

Atmospheric air is sometimes employed in thermometers. This fluid retains the gaseous state at all temperatures, is perfectly uniform in its expansion, and is extremely sensitive to changes of temperature. It is, however, affected also by changes of pressure, and is therefore a barometer as well as a thermometer.

367. *The differential thermometer* consists of two glass bulbs, A and B, connected by a glass tube, CD, to which is attached a graduated scale. The bulbs are filled with air, and a part of the tube is filled with a colored liquid. When the air in the two bulbs has the same temperature, one end of the column of liquid rests at the zero of the scale. When the bulbs have different temperatures, the liquid recedes from that side at which the temperature is greatest, and the extent of the motion is indicated by the graduated scale. This instrument is extremely sensitive, and indicates minute differences of temperature.

Fig. 213.



The invention of the thermometer is commonly ascribed to Sanctorius, a professor at Padua, in Italy, who claims to have invented, about 1590, an instrument with which he measured the temperature of the human body.

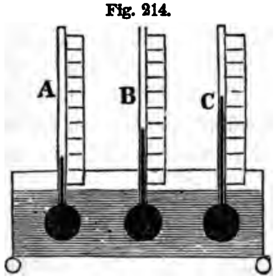
A Hollander, by the name of Drebbel, also invented a thermometer, perhaps independently, about the year 1610; but thermometers resembling in form those used at present, were first constructed in Florence about the year 1675.

368. *All liquids expand irregularly* as their temperature increases. Ten degrees of heat applied to a liquid at 200°, produce a greater expansion than when applied at 100°. No two

substances expand exactly alike through a great range of temperature. The expansion of different bodies can not, therefore, be exactly proportional to their change of temperature. The expansion of the mercurial thermometer is tolerably uniform up to 212°; above that point, the air thermometer is most reliable.

Different substances expand unequally for the same change of temperature.

Fig. 214.



Take several glass tubes, A, B, C, attached to bulbs of exactly the same size, and filled with different liquids to the same height. Let one be filled with alcohol, a second with sperm oil, and a third with water. When these are all immersed in the same vessel of hot water, the liquids will rise to different heights, the water being the lowest, the oil next, and the alcohol the highest. By being heated from 32° to 212°,

Mercury	expands	18	parts in	one thousand;
Water	"	43	"	"
Fixed oils	"	80	"	"
Alcohol	"	111	"	"

So, also, different *solid bodies expand unequally* for the same change of temperature. Thus, by being heated from 32° to 212°,

Flint glass	expands	811	parts in	one million;
Platinum	"	856	"	"
Steel	"	1189	"	"
Brass	"	1875	"	"
Silver	"	1890	"	"
Zinc	"	2942	"	"

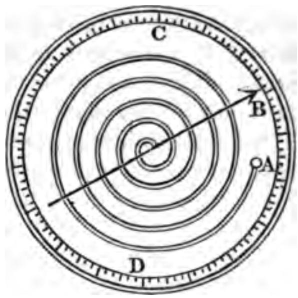
369. *Breguet's thermometer.* If a strip of brass be soldered to a strip of iron, so that the compound bar, AB, may be straight at the common temperature; when hot water is poured upon it, *it will bend*, the brass being on the convex side of the curve, as seen in CD. If it be cooled to a low temperature, the curvature will be in the other direction, the iron being on the convex side of the curve.

Fig. 215.

Such a compound strip of metal may be employed for meas-

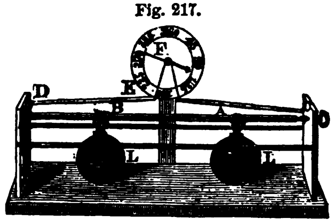
uring temperature. A slender strip of platinum is soldered to a strip of silver about $\frac{1}{100}$ inch thick, and is coiled into a spiral. One extremity is attached to a fixed support, A, while the other end carries an index, B, which moves over a graduated circle, CD. This thermometer may be made exceedingly sensitive, and very portable.

Fig. 216.



370. *For measuring very high temperatures, the pyrometer is employed.* This frequently consists of a metallic rod, AB, supported at one end by a fixed point, C, and at the other end, D, pressing against the shorter arm of a bent lever. To the longer end, E, of the lever is attached a cord, which passes round a wheel, on the centre of which is an index, F, and there is a graduated circle upon which the index travels. Spirit lamps, L, L, being placed beneath the rod, its expansion is shown by the motion of the index on the graduated circle.

Fig. 217.



371. *There is one apparent exception to the law of expansion by heat.* If we take water at the boiling point, and cool it, it contracts continually in bulk, until it arrives at the temperature of 39°, at which point all contraction ceases; and if the temperature be further reduced, the volume remains stationary for a moment, but a dilatation is soon produced, which continues until the water is congealed. *Water, therefore, attains its maximum density at* 39°; that is, if we take water at 39°, whether we warm it or cool it, it expands.

The expansion of water, as it approaches the freezing point, has been explained by supposing that the particles, when they crystallize and assume a solid state, have a tendency to unite by certain sides in preference to others. This arrangement of the particles, by leaving numerous pores, produces an enlargement of bulk.

This fact is one of great importance in nature. When, in

winter, a mass of water cools, the colder particles do not invariably descend to the bottom; but after attaining the temperature of 39°, they float on the top, and hence congelation begins at the surface; and the sheet of ice, once formed, protects the water below it from the further influence of cold.

If freezing began at the bottom, large reservoirs of water, during winter, would become solid blocks of ice, which the succeeding summer could not melt.

SECTION II.

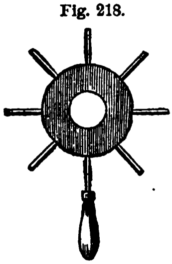
CONDUCTION AND RADIATION—CAPACITY FOR HEAT.

372. When a body is heated above surrounding objects, it loses heat in two ways, by *conduction* and by *radiation*.

When one end of a metallic bar is held in the flame of a lamp, the temperature of the other end rises. The heat gradually diffuses itself from one particle to another, and is said to be *conducted*.

A piece of wood which is burning at one end, becomes but slightly heated at the remote end; hence some bodies are *good*, others *bad conductors* of heat. This is indicated by the following experiment.

Fig. 218.



Take a circular plate of brass, having its edge perforated with holes, in which are inserted rods of different metals of the same size and length, each having near its extremity a small cavity for containing a piece of phosphorus. On holding the plate over the flame of a spirit lamp, the heat is conducted along the different rods, inflaming the phosphorus first in that which is the best conductor, and subsequently in the others, in the order of their conducting power. The order of the rods commonly is *copper, brass, iron, zinc, tin, lead, and glass.*

373. The metals are the best conductors of heat; glass and clay are poor conductors.

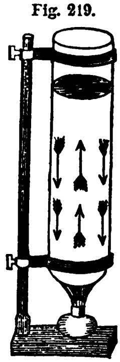
The following experiment shows the difference between the

conducting power of metal and wood. Take a metallic cylinder about one inch in diameter, wrap a piece of writing paper close round the metal, and then hold it in the flame of a spirit lamp. The heat which is applied to the paper will be conducted off by the metal, and the paper can not be burned until the metal becomes very hot; but if we wrap the paper around a cylinder of wood, and hold it in a lamp, it will speedily burn.

Liquids are bad conductors of heat, and gases are still more imperfect.

374. Water is ordinarily heated, not by conduction, but *by circulation*. When the water in contact with the bottom of a vessel is heated, it expands, and becomes lighter than the strata over it. It therefore rises, and the water above it descends, and this, in its turn, being expanded by heat, is made to rise. There is thus a continued current of the heated water upward, and a counter current of the colder water downward. This may be exhibited in the following manner. Fill a flask with cold water, and put into it some particles of amber. The amber, having nearly the same specific gravity as the water, will remain suspended in it. Place a spirit lamp under the flask, and the currents in the water will immediately appear.

Fig. 219.



375. *All bodies radiate heat* from their surfaces. These rays, like rays of light, may be reflected or absorbed by other bodies.

The heat of a hot ball is sensible at a considerable distance, and may be made to affect a thermometer.

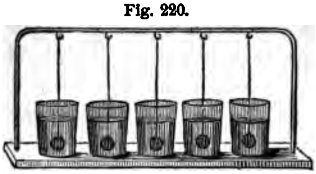
The rate at which a hot body loses its heat, is proportional to the difference between its own temperature and that of the surrounding medium. Rough surfaces radiate heat more rapidly than smooth surfaces. When the rays of heat encounter a material surface, they are more or less reflected from it, and the angle of reflection is equal to the angle of incidence.

If the rays of a hot body be received upon a concave reflector, they will be collected in the focus of the mirror, as may be shown by the effect upon a thermometer or any combustible body. The rays of the sun reflected from a concave mirror of 6 or 8 inches in diameter, may be made to ignite phosphorus or gunpowder.

376. *Capacity for heat.* The thermometer does not measure *the quantity of heat* present in a body, but only indicates *its intensity*. Two bodies may contain very different quantities of heat, although the thermometer indicates the same temperature. Different bodies (as, for example, water and mercury) require different quantities of heat to produce a given change of temperature, and hence they are said to have different *capacities* for heat. If we mix a pint of water at 40° with a pint of water at 100°, the temperature of the mixture will be 70°; but if we mix a pint of water at 40° with a pint of mercury at 100°, the temperature of the mixture will be only 60°, showing that 40° of the heat of the mercury have raised the water only 20°. Hence *the capacity of water for heat is twice as great as that of mercury, when equal volumes are compared, but twenty-three times as great if equal weights are compared.*

377. The capacity of different metals for heat may be tried in the following manner. Take several glass tumblers, each containing the same quantity of cold water, and all at the same temperature. Also take an equal number of balls of different metals, having exactly the same weight. Let one of the balls be of lead, one of tin, one of copper, and two of iron. Immerse them all for a time in boiling water, and then suspend each of them in one of the tumblers. We shall find that the lead will raise the temperature of the water the least, the tin somewhat more, the copper more yet, and the iron most of all, each of the iron balls imparting the same amount of heat. Hence the capacity of these substances for heat is in the following order: lead, tin, copper, and iron; the capacity of iron for heat being about double that of tin.

Fig. 220.



Hydrogen, the lightest of all bodies, *has the greatest capacity for heat*, and the metals have the least capacity.

378. *By increasing the density of a body, its capacity for heat is diminished*, and a quantity of heat is set free. Thus, when air is suddenly condensed in a syringe, heat is evolved sufficient to inflame tinder.

On the contrary, *when air is rarefied, its capacity for heat is in-*

creased, and a thermometer indicates a reduction of temperature. This may be shown with the exhausted receiver of an air pump. When moist air in the receiver is suddenly rarefied, a fog or cloud is perceived. This cloud is due to the precipitation of a part of the vapor present in the air, in consequence of the sudden cold produced by rarefaction. A thermometer placed under the receiver almost immediately falls several degrees.

SECTION III.

LATENT HEAT—LIQUEFACTION AND VAPORIZATION.

379. *Fluid bodies contain a large amount of heat which does not affect the thermometer.* Suppose a mass of ice, of the temperature of 20°, to be brought into a warm room. The temperature of the ice will gradually rise to 32°; it will then begin to melt; but, during the process of melting, which may occupy several hours, the temperature of the mass will never rise above 32°. The ice continues to receive heat as rapidly as at first; and since there is no increase of sensible temperature above 32°, we conclude that heat must have been employed in transforming the ice from the solid to the liquid state. *This heat is called latent heat.*

If we mingle a pound of snow at 32° with a pound of water at 174°, the compound will be water having a temperature of 32°. Hence water at the temperature of 32° contains 142° more of heat than ice at 32°; that is, *the latent heat of water is* 142°.

380. *Latent heat of steam.* Let a spirit lamp be placed under a vessel containing water at 32°, and observe the time required to raise the water to 212°. If the lamp supplies heat in a uniform manner until all the water has been converted into steam, it will be found that the time required for the entire evaporation, will be 5½ times that which was required to raise the water from the freezing to the boiling point, and the temperature of the water will at no time rise above 212°. Hence, in the evaporation of water, the amount of heat absorbed is 5½ times as great as is required to raise the water through 180° of temperature; that is, *steam at* 212° *contains* 990° *of latent heat.*

When this vapor returns to the liquid condition, the same amount of heat is liberated. Thus, if we distill one pint of water, and condense the vapor in ten pints of cold water, they will be heated 99°.

381. *Freezing mixtures.* All bodies absorb heat when they pass from the solid to the fluid state. This principle explains the effect of several processes for the production of cold.

If we mix together equal weights of snow and common salt at 32°, they will liquefy, and the temperature will fall to —9°. Such a compound is called a *freezing mixture.* Snow and salt have a strong affinity for each other, and when they combine they form a liquid. But, in order that snow may become a liquid, it must receive a large amount of latent heat. This heat is abstracted from the mixture itself, and its sensible temperature is thereby reduced.

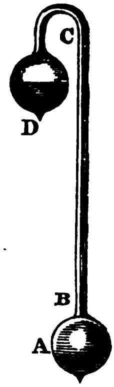
When ether is poured on the hand, it rapidly evaporates, producing the sensation of cold; for the ether can not pass into the state of vapor until it receives a large amount of latent heat, and this heat it abstracts from the hand. If we pour ether upon the bulb of a thermometer, the mercury will sink rapidly, showing that the sensation of cold experienced by the hand was not an illusion; or, if we pour ether upon the bulb of the air thermometer, the liquid will rise higher in the tube.

382. *Water may be frozen by its own evaporation.* For this purpose, fill a watch glass, or a small shallow dish, A, with water, and place it over a shallow vessel, B, filled with sulphuric acid, and cover the whole with the receiver of the air pump. Upon exhausting the air, vapor rises from the water and is absorbed by the acid, thereby permitting the formation of a farther supply of vapor, which occasions such a degree of cold as to freeze the water in a short time.

Fig. 221.

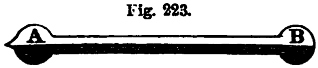
Wollaston's cryophorus, or *frost-bearer,* also illustrates the effect of evaporation in producing cold. This instrument consists of a glass tube, BC, about 18 inches long, and one fourth inch in diameter, bent near one end, and terminated at each end by a bulb. In constructing this instrument, one of the bulbs is partly filled

Fig. 222.



with water, and is then boiled until the air is expelled by the steam, when the open bulb is closed by melting the point in a spirit lamp. When the water is driven into the upper bulb, D, and the lower bulb, A, is immersed in a mixture of salt and snow, the vapor within it is condensed, and a vacuum is produced, which, by removing the pressure from the surface of the water in the upper bulb, causes it to evaporate rapidly, and, the vapor being condensed in the lower bulb as speedily as it is formed, the water is soon frozen.

Fig. 223.



The *pulse glass* consists of a glass tube, A B, terminated at each end by a bulb, partially filled with spirit of wine. When it was closed by the blow-pipe, the air was mostly expelled by boiling the spirit of wine, so that the air remaining within is very rare. If we hold the tube in a slightly inclined position, and grasp the lower bulb in the hand, the warmth of the hand is sufficient to expand the air and the vapor mixed with it, which, by forcing the liquid over to the other end, produces a bubbling similar to that of boiling water. At the same time, a sensation of cold is felt in the hand, on account of the heat which is withdrawn to enable the spirit of wine to assume the state of vapor.

383. All liquids, with the exception of alcohol, have been reduced to the solid state, and all solids that do not suffer decomposition at low temperatures may be converted into fluids, and most of them into vapor. Different solids are fused at different temperatures; but the same solid is always fused at the same temperature, which temperature is called its *point of fusion*.

Alloys, composed of the mixture of two or more metals, *frequently liquefy at a lower temperature than either of their constituents*. An alloy composed of 8 parts of bismuth, 5 of lead, and 3 of tin, liquefies at a temperature below that of boiling water, although neither of these metals by itself fuses at a temperature below 430°.

384. *Vapor of water is an elastic transparent fluid like air.*

This is shown by the following experiment. Take a flask filled with water, and, having inverted it in a jar of water, introduce

into it a little sulphuric ether. Upon heating the flask by pouring hot water upon it, the ether will be converted into vapor, which expands and fills the flask. From this experiment, we see that vapor occupies much more space than the liquid from which it rises. When the temperature of the vapor is reduced by pouring cold water upon the flask, the vapor suddenly returns to the liquid state.

It was formerly supposed that vapor is supported in the air as water is supported by a sponge; or that air dissolves vapor as water dissolves salt or sugar. That such a view is erroneous, is proved by the fact that *evaporation takes place in a vacuum;* and *the presence of air not only does not promote evaporation, but actually retards it.* This is shown by introducing ether or water into the vacuum of a barometer tube, when a portion of the liquid immediately passes into the state of vapor, and by its elastic force causes a depression of the column of mercury. Vapor of water, therefore, supports itself, just as atmospheric air sustains itself.

385. *Elastic force of vapor.* By introducing a little water into the Torricellian vacuum, and surrounding the tube with a vessel containing water heated to different temperatures, and observing the depression of the mercury, we may determine the elastic force of vapor at all temperatures from 32° to 212°. The following are a few of the results of such experiments.

At the temperature of		212°,	the elastic force of vapor of water is equal to a pressure of 30 inches of mercury,		
"	"	180°,	15	"	"
"	"	150°,	8	"	"
"	"	127°,	4	"	"
"	"	103°,	2	"	"
"	"	80°,	1	"	"
"	"	59°,	$\frac{1}{2}$	"	"
"	"	32°,	$\frac{1}{5}$	"	"

Evaporation goes on at all temperatures, even the lowest. Even when water is frozen, vapor rises from it, exerting an appreciable pressure. At the temperature of zero of Fahrenheit, the elastic force of the vapor of water is $\frac{1}{16}$ inch of mercury.

386. *The boiling point of water varies with the pressure.* When

subject to a pressure of 30 inches of mercury, the boiling point is 212°. Under diminished pressure it boils at a lower temperature. This is shown in the following experiment. Pour a small quantity of water into a retort, and apply the heat of a lamp until it boils. Permit the boiling to continue long enough to expel the air; then cork the retort and remove the lamp. As the retort cools, and the vapor becomes condensed, the pressure on the surface of the water diminishes, and the water boils at a temperature much below 212°. If we heat the retort while it is tightly corked, new vapor will rise, which produces pressure on the surface of the water, and stops the ebullition; that is, by cooling the retort we make the water boil, and by heating it again we stop the ebullition. This is best shown by plunging the retort into a jar containing hot and cold water alternately. Water will boil when the elastic force of the vapor formed is equal to the pressure to which it is subjected. Hence, under the pressures expressed in column second of the table in Art. 385, water will boil at the temperatures given in column first.

387. *When the pressure on the surface of the water is greater than* 30 *inches of mercury, the boiling point rises.* Take a stout and close vessel half filled with water, having a thermometer to indicate the temperature of the water, and a gauge to show the amount of pressure. By heating the water, we may determine the boiling point for pressures greater than one atmosphere. The following are the results of such experiments:

Under a	pressure of	1	atmosphere,	the	boiling point is	212°.
"	"	1½	"	"	"	234°.
"	"	2	"	"	"	250°.
"	"	2½	"	"	"	264°.
"	"	3	"	"	"	275°.
"	"	4	"	"	"	294°.
"	"	5	"	"	"	307°.

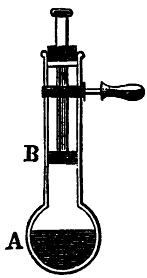
SECTION IV.

STEAM-ENGINE.

388. *A cubic inch of water, when converted into steam at the usual atmospheric pressure, will form nearly a cubic foot of steam;* and if a cubic foot of such steam be cooled, it will be reconverted into a cubic inch of water, and a void space of 1727 cubic inches will be left.

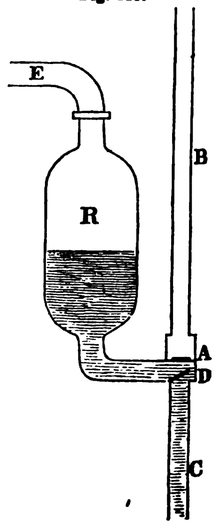
This principle explains the following experiment. Take a glass tube terminating in a bulb, A, and having a piston, B, working steam-tight in the tube. Introduce into the bulb a little water, and boil it by means of a spirit lamp. The piston will be forced upward by the pressure of the steam; but, on dipping the bulb in cold water, the steam will be condensed, and the piston be forced down by the pressure of the atmosphere.

Fig. 224.



Upon boiling the water a second time, the piston will be again forced upward, but it will fall as soon as the steam is condensed. This apparatus exhibits *the essential principle of the steam-engine.*

Fig. 225.



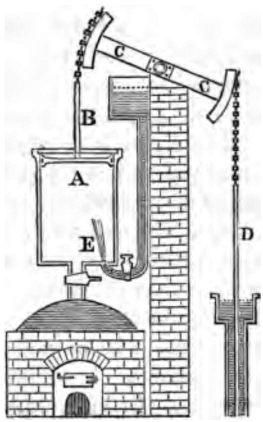
389. *The first steam-engine which properly deserved the name was constructed by Savary,* and it was chiefly used for draining the mines of England. A large close vessel, R, was filled with steam, proceeding from a boiler through the pipe E, by which means the air was expelled, and escaped through a valve, A, which opened upward into a long tube, B, leading to the top of the mine. The steam was then condensed by cooling the external surface of the vessel, R, by means of a stream of cold water. A vacuum was thus produced in the vessel R, into which the air could not enter, because the valve A

opens upward. The pressure of the atmosphere on the surface of the water in a reservoir at the bottom of the mine, therefore forced the water up the tube C, through the valve D, into the vessel R, which thus became filled with water. Steam proceeding from the boiler was then admitted through the pipe E, which, pressing on the surface of the water in R, forced the water out of the vessel up the pipe B. When the water had all been driven from the vessel R, and its place was supplied by steam, the steam was again condensed by a stream of cold water, forming a vacuum, into which water from the reservoir was forced by the pressure of the atmosphere. This water was driven out by the elastic force of steam, and so on as before. This engine was invented in 1698.

Savary's engine had several serious defects.

1st. The vessel R could not be made to bear a pressure greater than 30 lbs. per square inch, and this pressure was barely sufficient to lift a column of water 90 feet high. In order to raise water from the bottom of a mine by these engines, it was therefore necessary to place an engine for every 90 feet of the depth. 2d. The consumption of fuel was enormous; for when the steam was first introduced into the vessel R, it must heat the vessel up to the temperature of the steam itself, otherwise the steam would be immediately condensed. All this heat spent in raising the temperature of the vessel was wasted, being dissipated by the subsequent process of condensation.

Fig. 226.



390. *Savary's engine was succeeded in 1713 by the atmospheric engine of Newcomen.* Newcomen proposed to raise water from the mines by means of a pump, and to work the pump by the power of steam. For this purpose he employed a cylinder, A, and a piston, B, moving in it steam-tight. He connected the piston-rod with one end of a great beam, CC, oscillating upon its centre, the other end of the beam being connected with the rod of a pump, D, which he proposed to work. The

weight of the pump-rod was sufficient to draw the piston to the top of the cylinder. The cylinder was then filled with steam, by which means the air was expelled. The cylinder was then cooled by a jet of cold water, E, by which means the steam was condensed, and a vacuum was produced beneath the piston. The pressure of the atmosphere immediately forced the piston down, and drew up the pump-rod at the opposite end of the beam. Steam was again admitted below the piston, which was forced up as before, and thus the process continued. Newcomen's engine had several advantages over Savary's. It might be worked with steam of less tension, and therefore the boiler was less liable to burst; it was also far more powerful, and at the same time more economical. *This engine was superseded by Watt's condensing engine in* 1763.

391. *High pressure steam-engine described.* In all modern engines, steam is employed both above and below the piston alternately. The simplest form of engine now used is the *high pressure engine.* It consists of a very strong vessel or boiler, in which the steam is generated; a cylinder, in which a piston moves forward and backward steam-tight; and an arrangement of valves, so adjusted as to admit the steam alternately at the top and bottom of the cylinder, and to allow the steam to escape into the open air as soon as it has done its work upon the piston.

To the boiler is adapted a safety valve opening outward, and loaded with a weight such that the valve shall remain closed at ordinary pressures; but when the pressure of the steam becomes greater than can be borne with safety, the valve opens, and allows the steam to escape.

The steam is conveyed from the boiler to the cylinder in a large pipe, having a valve called *the throttle valve,* by which the steam may be entirely cut off, or its supply regulated at pleasure.

392. *The slide valve.* If steam is admitted at the top of the cylinder, and the escape valve is opened at the bottom of the cylinder, the piston will be driven to the bottom of the cylinder. If new steam be admitted at the bottom of the cylinder, and the escape valve be opened at the top of the cylinder, while that at the bottom is closed, the piston will be forced to the top of the cylinder. In order to produce the reciprocating motion of the

piston, it is therefore only necessary that steam be admitted alternately at the top and bottom of the cylinder, while the escape valves are opened and closed in their proper order. This may be effected by an arrangement called *the slide valve*. DE represents the valve-box, to which steam from the boiler is admitted by the tube S. Two curved passages, AA, BB, communicate between this valve-box and the top and bottom of the cylinder, while another passage leads to the tube C, which communicates with the external air. A small sliding piece, F, within the valve-box, opens a communication alternately between each end of the cylinder and the tube C. In the position of the slide F shown in *Fig.* 227, steam passes from the boiler through the curved passage AA, above the piston, and at the same time the steam below the piston passes through the passage BB into the tube C, and thence to the external air. Thus steam is introduced above the piston, and the steam below the piston is permitted to escape. The piston therefore descends, and as soon as it arrives at the bottom of the cylinder, the slide is moved into the position represented in *Fig.* 228. Steam now passes from the boiler through BB below the piston, and the steam above the piston passes through AA and C to the external air. Thus steam is introduced below the piston, and the steam above the piston is permitted to escape. The piston therefore ascends, and thus the motion may be continued indefinitely, provided the sliding piece within the valve-box DE is properly adjusted.

Fig. 227.

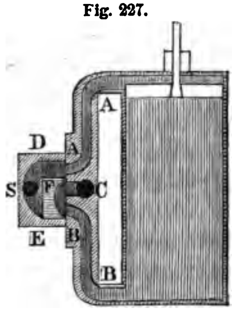
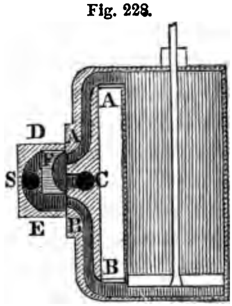


Fig. 228.



393. *The eccentric.* The slide F is controlled by the machinery in the following manner. GH represents a metallic ring, whose inner surface is perfectly smooth and circular. This ring is connected with a shaft, IK,

Fig. 229.

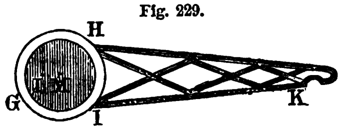
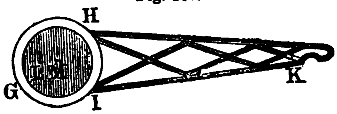


Fig. 230.



which communicates motion to the slide by a lever, one arm of which is attached to the shaft at K. A circular metallic plate is fitted to the ring, so as to be capable of turning smoothly within it. This circular plate revolves, but not on its centre. It turns on an axis, L, at some distance from its centre, M, the result of which is that the ring within which it turns, is moved alternately in opposite directions through a space equal to twice LM. This apparatus is called *an eccentric*. The plate and ring are fitted to the axis of the fly-wheel, so that the rotation of the fly-wheel produces a reciprocating motion in the shaft IK, and this moves the slide F in the valve-box DE.

The piston is connected with one end of a beam which oscillates around its centre, while the other end turns a crank which gives motion to a heavy cylindrical shaft. On a steam-boat, the paddle-wheels are attached to this shaft.

In order that the piston-rod may move back and forth in a straight line without straining the cylinder, there is attached to the extremity of the piston-rod a cross-bar, the ends of which are made to slide in fixed grooves.

During every revolution of the crank, there are two positions in which the steam has no power to turn the crank, and the motion is liable to be arrested. To prevent such a result, there is attached to the axis of the crank a heavy *fly-wheel*, which, by its inertia, carries the crank beyond the dead points, and maintains a tolerably uniform motion of the machinery.

In the high pressure engine, the piston moves both ways against the pressure of the air. The steam must therefore necessarily have an elasticity considerably greater than that of the atmospheric air.

On account of the difficulty of condensing the steam, only high pressure engines are used on rail-roads; and they are almost exclusively used on the steam-boats of the Mississippi and its tributaries.

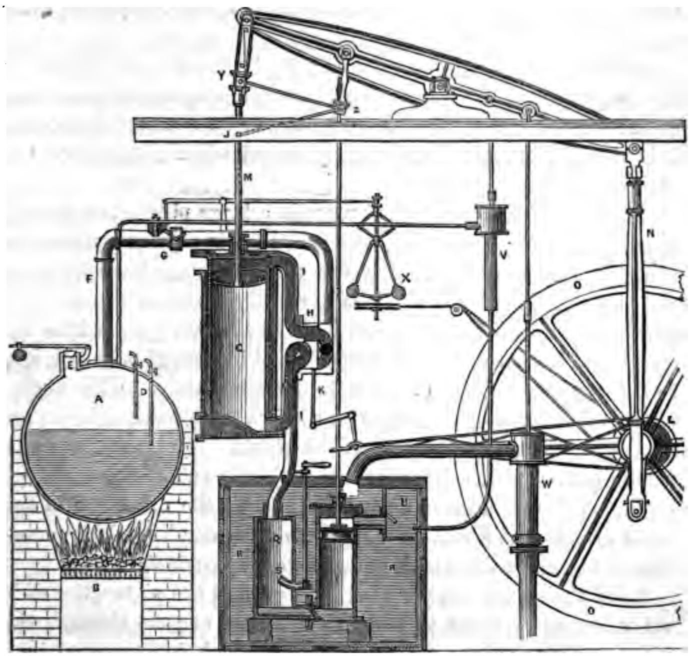
394. *Low pressure steam-engine described.* The *low pressure* engine differs from the high pressure in having a *condenser* for the steam. This engine is still constructed substantially in the

mode invented by Watt in 1763. After the steam has communicated motion to the piston, instead of being forced out of the cylinder against the pressure of the air, a communication is opened with a separate vessel, into which is forced a jet of cold water, by which the steam is suddenly condensed. Thus a vacuum is created upon one side of the piston, and the entire pressure of the steam upon the other side is effectual in producing motion.

The following is an enumeration of the principal parts of Watt's double acting engine.

The boiler, A, is of a cylindrical form, and is made of thick

Fig. 231.



plates of rolled iron; the fire is kindled in a grate beneath, B, and there are dampers to regulate the draft. The boiler is filled about two thirds full of water, and the space above it is occupied with steam. Two tubes, D, with stoppers, are inserted near one end of the boiler, one descending below the surface of the water, and

the other terminating above it. If the water stands at its intended level, when the shorter tube is opened, steam will escape, and when the longer tube is opened, water will escape. If the water is too high, it will escape from both tubes; if the water is too low, steam will escape from both. The boiler is continually replenished with water by means of a force pump worked by the machinery.

Connected with the boiler is a barometer gauge to show the pressure of the steam. In the top of the boiler is an opening, to which is fitted *a safety valve*, E, which is loaded with a weight, so that, if the pressure of the steam in the boiler should become too great, the valve opens of itself, and the steam escapes into the open air.

In order that access may be had to the interior of the boiler for the purpose of clearing it from incrustations of salt and other deposits, there is a large plate, which may be removed whenever it is desired, but which is securely closed when the boiler is in use.

From the top of the boiler proceeds a large pipe, F, to convey steam to the cylinder of the engine. In this pipe is a valve, G, called the *throttle valve*, by which the pipe may be opened or closed at pleasure, but which is generally made to regulate itself by means of the governor, X. The steam passes into *the valve-box*, H, from whence it is conducted by curved passages, I, I, to the top and bottom of the cylinder alternately. This movement is regulated by the *slide valve*, K, which is worked by an *eccentric*, L, turning on the axis of the crank.

The piston-rod, M, is connected with one end of the working-beam, which oscillates upon its centre. To the other end of the beam is attached a rod, N, which turns the crank, giving revolution to an axis with which is connected *a fly-wheel*, OO.

After the steam has elevated or depressed the piston, the slide valve is moved so as to permit the steam to pass through the eduction pipe, P, into *the condenser*, Q, which is immersed in a cistern of cold water, RR. By means of a jet of cold water, which passes through the injection pipe, S, the steam is here condensed into water. The warm water resulting from the condensation is pumped out by an *air-pump*, T, into the *hot well*, U, from which it is expelled by a force pump, V, into the boiler, to sup-

ply the waste from evaporation. *A cold-water pump*, W, supplies the reservoir with cold water. These three pumps are worked by the beam of the engine.

Connected with the axis of the fly-wheel is a *governor*, X, which controls the throttle valve, G, and thus regulates the supply of steam to the cylinder. If the engine works too fast, the balls of the governor by their centrifugal force are thrown outward, and pull upon one arm of a lever which turns the throttle valve, and cuts off or checks the supply of steam. If the engine goes too slow, the balls of the governor fall to the lowest point, and by means of the same lever the throttle valve is entirely opened.

In order that the piston-rod may move up and down in a straight line without straining the cylinder, Watt invented a contrivance called the *parallel motion*. The piston-rod is attached to one angle, Y, of a parallelogram, the upper side of which is formed by the working-beam, and the other angle, Z, of the lower side is connected by a rod with a fixed support, J.

395. *The force of a steam-engine is commonly estimated according to a scale in which the supposed power of one horse is the unit.* By one horse-power is understood a force sufficient to raise 33,000 pounds one foot high in one minute; this being found, by experment, to be the performance of a horse of average strength working for eight hours a day. In the steam-boats of the United States, it is common to allow one horse-power to 2¾ tons; that is, a boat of 1000 tons would require an engine of 360 horse-power.

396. *The advantage resulting from the use of a condenser* depends upon the tension of the steam employed. If the steam press on one side of the piston with a force of only one atmosphere, while the external air communicates freely with the other side, the two pressures will be equal, and no motion will ensue. If, therefore, the steam has a tension of but one atmosphere or a little more, a condenser is indispensably necessary. If the tension of the steam is equal to two atmospheres, and the air presses on the opposite side of the piston, the effect will be the same as if there were a vacuum on one side of the piston, and the steam pressed upon the other side with the force of one atmosphere, one half of the power of the steam being lost in overcoming the resistance of the air.

If the tension of the steam were equal to 3, 4, 5, etc. atmospheres, and there be no condenser, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, etc. of this power would be lost in overcoming the resistance of the air. The greater is the tension of the steam, the less will be the loss of power in overcoming the resistance of the air when there is no condenser. A portion of the power of the steam is necessarily employed in working the air-pump of the condenser. At a certain pressure of steam, the resistance of the air-pump just balances the advantage gained by the condenser; and if we use steam of still higher tension, the condenser is worse than useless.

397. *Expansive action of steam.* In most engines, the supply of steam to the cylinder is cut off when the piston has traversed a portion of its course, and the piston is driven to the end of the cylinder by *the expansion of the steam already supplied.* If steam, having a tension of two atmospheres, is supplied to the cylinder during the entire descent of the piston, the cylinder will be entirely filled with steam of two atmospheres, and during the motion of the piston, there will be produced a certain mechanical effect which we will designate by X. If now we admit into the cylinder, steam having an elastic force of four atmospheres, the pressure upon the piston will be twice as great as before, and the effect X will be produced when the piston has reached the middle of the cylinder. If, at this instant, the supply of steam be cut off, the piston will continue its motion from the expansion of the steam already admitted, and when it reaches the end of the cylinder, its tension will still be two atmospheres. The effect produced during the second half of the piston's motion is so much gained beyond the effect X; and the weight of steam filling the cylinder at the end of the piston's motion, is the same as if steam having a tension of two atmospheres had been supplied during the entire motion of the piston. Hence we see that, with a given weight of steam, a considerable increase of power is produced by cutting off the steam after the piston has made a part of its descent, and allowing the remainder of the descent to be produced by the expansive force of the steam already admitted.

It is common to cut off the supply of steam when the piston has completed one third or one fourth of its motion; in some of the Cornish engines, the steam is cut off at one fifth, and in others even at one tenth of the stroke.

BOOK SIXTH.

OPTICS.

SECTION I.

DEFINITIONS—SHADOWS—PHOTOMETRY.

398. *Optics is the science which treats of the properties of light.*

Light is the physical agent by which external objects are rendered manifest to the sense of sight. Two different theories have been proposed to account for the phenomena of light. One, which is called *the theory of emission*, regards light as consisting of exceedingly minute particles of matter, projected by the luminous body in all directions with prodigious velocity. The other, which is called *the wave theory*, assumes that all space is pervaded by a medium of extreme tenuity; that luminous bodies possess the power of exciting vibrations in this medium, and that these vibrations constitute light.

Most of the terms employed in optics are borrowed from the former theory; but the discussion of these theories must be deferred until the chief properties of light have been explained.

Bodies which possess the power of exciting the sensation of light are said to be *luminous*. Certain bodies possess in themselves this power, and are hence called *self-luminous*, as the sun, the stars, the flame of a lamp, etc. *Non-luminous* bodies emit no light, but are rendered temporarily luminous when placed in the presence of luminous bodies. A lighted candle renders the walls and furniture of a room temporarily luminous.

399. Any space or substance through which light may be transmitted is called *a medium*. Glass, water, air, etc., are media.

There is no substance, however transparent, which does not intercept some portion of light. A very thin plate of glass is almost perfectly transparent; but as the thickness is increased, the transparency is diminished. The distinctness with which distant terrestrial objects are seen, diminishes as their distance in-

creases; because a portion of the light which they transmit is absorbed in its progress through the atmosphere. It is estimated that the atmosphere would be impervious to the sun's light, if it had a depth of 700 miles.

Bodies are said to be *semi-transparent* when light passes through them so imperfectly that the forms of objects behind them can not be distinguished, such as ground glass, horn, paper, etc.

A luminous body transmits or *radiates* light in all directions, for it is visible in all positions of the eye if the light be not intercepted.

400. In a uniform medium, *light is propagated in straight lines.* This is proved by the following experiment. If an opaque object be interposed in a right line between the eye and a luminous point, the point will cease to be visible. The path of a sunbeam admitted into a dark room is seen to be straight.

Any straight line along which light is admitted is called a *ray of light.* A collection of parallel rays is called a *beam of light.* A collection of contiguous rays, emanating from a luminous point, is called a *pencil of light.* When rays radiate from a luminous point, they are called *diverging rays.* When rays converge to a common point, they are called *converging rays.* The point of meeting of all the rays of a pencil is called *the focus* of the pencil.

401. *Shadows and penumbræ.* When light radiating from a luminous point, A, encounters an opaque body, B, it is excluded from the space behind the body, and thus a shadow is formed. If the opaque object be a sphere, the shadow CD EF will be a truncated cone. All luminous objects have more or less extent, and therefore consist of a great number of luminous points. Now each luminous point is the focus of an independent pencil of luminous rays, and each pencil produces an independent shadow. Let AB represent the section of a luminous body, and CD the section of an opaque object. From every point of AB will issue a pencil of rays of light. The pencil which

Fig. 232.

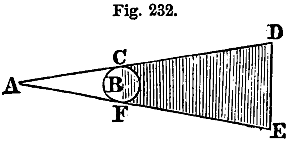
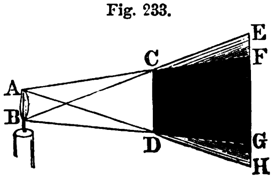


Fig. 233.



issues from the point A will encounter the object CD, and the extreme rays grazing the edge of the object will proceed in the directions AF, AH; that is, the light proceeding from the point A will be excluded from the space between the lines CF and DH. So, also, the light issuing from the point B will be excluded from the space between the lines CE, DG. All the light proceeding from points between A and B, will be excluded from the space between the lines CF and DG, while more or less light will enter the space between the lines CE and CF; as, also, DG and DH.

The space included between the lines CF and DG is called *the umbra*, or absolute shadow; while the space included between CE and CF, and between DG and DH, from which the light of the luminary is only partially excluded, is called *the penumbra*, or imperfect shadow. The obscurity of the penumbra increases gradually from its outer limit to the limit of the umbra, where the obscurity becomes complete.

402. *The intensity of the light received from a luminous body varies inversely as the square of the distance.* Suppose there are two spheres having a luminous point as their common centre, and the radius of one double the radius of the other. Since the surfaces of spheres vary as the squares of their radii, the surface of the greater sphere will be four times that of the less. Now, since all the light which issues from the luminous point is diffused over the surface of the sphere, its density on the surface of the less sphere will be to its density on the surface of the greater sphere, as 4 to 1, or inversely as the square of the distance from the luminous point.

This principle may be verified experimentally as follows: Take four sperm candles, each furnishing the same amount of light, and place them close together, so that they may be regarded as a single light. At any convenient distance place a white screen, and also a small opaque object, casting its shadow upon the screen. Take a fifth candle, and place it before the screen, so that its shadow shall just touch the former shadow, without overlapping, and place it at such a distance that the two shadows shall appear of the same brightness. We shall then find that the distance of the four candles from the screen is double that of the single candle.

403. This principle enables us to *compare experimentally the illuminating power of two different lights.* For this purpose, place two pieces of paper side by side in such a manner that each may be illumined by one of the lights exclusively. We must then vary the distance of the lights until the two papers appear of equal brightness. The illuminating power of the lights will then be in the ratio of the squares of their distance from the papers.

404. Another method of comparing the illuminating power of two lights is by means of *their shadows.* Place a small opaque object at a short distance from a white screen, and place the two lights which are to be compared, so that the two shadows which they cast shall just touch, without overlapping each other. Two spaces will appear on the screen in juxtaposition, each of which is illumined by one of the lights independently of the other. If the two spaces appear unequally bright, the position of the opaque object or of the lights must be changed until both shadows appear equally bright. The distances of the two lights from the shadows must then be measured, and the illuminating power of the lights will be as the squares of these distances. For example, if the shadow of a metallic rod, placed in the light of a sperm candle at the distance of 3 feet, has the same brightness as the shadow of the same rod in the light of a gas flame at the distance of 12 feet, then the illuminating power of the candle is to that of the gas as 1 to 16.

SECTION II.

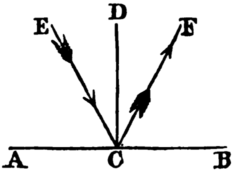
REFLECTION OF LIGHT.

405. When rays of light meet the surface of an opaque body, a portion of them are absorbed, and the remainder are turned back into the medium from which the rays proceeded, and are said to be *reflected.* Surfaces which possess this power of reflecting light in the highest degree are called *mirrors*, or *specula.* The best specula are composed of metals, such as alloys of copper, silver, and tin.

Let AB be a reflecting surface, upon which falls a ray of light, EC. Draw the line CD perpendicular to the reflecting surface

at C. The angle DCE is called the *angle of incidence.* Let CF be the direction in which the ray is reflected from AB. The angle DCF is called the *angle of reflection.* The plane of the angle DCE is called the *plane of incidence;* and the plane of the angle CDF is called the *plane of reflection.*

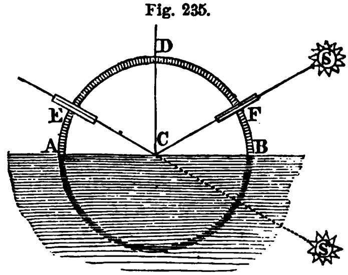
Fig. 234.



406. When light is reflected from a perfectly polished plane surface, *the angle of incidence is equal to the angle of reflection, and both angles are situated in the same plane.* This law may be verified as follows:

Let a graduated circle be placed in a vertical plane in a basin of mercury, so that its centre, C, shall coincide with the horizontal surface of the liquid AB, and let the circle be furnished with two movable tubes, E and F, revolving as radii of the circle. If now the tube F be directed to the sun, S, it will be found that the reflected ray will not pass through the tube E unless the plane of the circle pass through the sun, and the angle ECD, measured on the graduated circle, be equal to FCD. If the observer look through the tube E, the image of the sun will be observed in the direction CS′, and will appear as much below the surface of the mercury as the real sun is above it. Hence it follows that the plane of reflection, DCE, coincides with the plane of incidence, DCF, and the angle of reflection, DCE, is equal to the angle of incidence, DCF.

Fig. 235.



If parallel rays be received upon a plane reflecting surface, they will be parallel after reflection.

407. *If a pencil of rays diverging from a point,* A, *fall upon a plane mirror,* BC, *the reflected rays will appear to proceed from a point,* D, *situated behind the mirror similarly placed, and at the same distance as the focus of incident rays is before it.* Each of the rays, AE, AF, etc., will have its an-

Fig. 236.

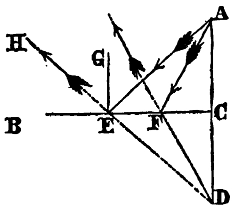
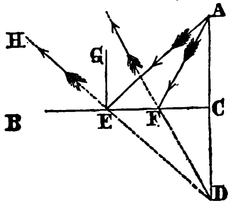


Fig. 237.



gle of reflection, GEH, etc., equal to its angle of incidence, GEA; consequently their complements, HEB, AEC, will be equal. Draw AC perpendicular to BC, and produce it to D, to intersect the reflected ray HE, produced backward.

The angle AEC is equal to HEB, which is equal to its vertical angle DEC. Also the right angle ACE is equal to DCE, and EC is common to the two triangles ACE, DCE; therefore AC is equal to CD. Since similar reasoning applies to every ray proceeding from A, and falling upon the mirror BC, it is evident that the reflected pencil will appear to come from the point D.

Hence, if an object be placed before a plane mirror, its image will be formed at an equal distance behind the mirror; for the rays proceeding from the object will, after reflection, diverge from points having corresponding positions behind the mirror.

408. The image of an object seen in a plane mirror appears *erect;* that is, the top of the image corresponds with the top of the object, and the bottom of the image with the bottom of the object; but the image is reversed as respects right and left. Thus, if a person stands with his face to a plane mirror, the image of his right hand will be on the right side of his image as he views it, but will be on the left side of the image itself.

So, also, if we hold a printed book before a plane mirror, all the letters appear reversed as respects right and left.

If an object placed before a plane mirror be not parallel with it, the image will form an equal angle with the mirror. If the mirror be horizontal, the image of any vertical object seen in it will appear inverted. Thus, on the bank of a tranquil lake, objects appear inverted by reflection from the surface of the water.

409. *If an object be placed between two parallel plane mirrors, there will be formed a series of images, all situated on the straight line drawn through the object perpendicular to the mirror.* Let AB and CD be two parallel mirrors, and E an object placed between them. An

Fig. 238.

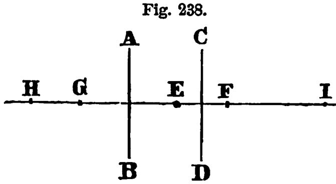


image of E will be formed at F, as far behind CD as E is before it, and another image will be formed at G, as far behind AB as E is before it. An image of F will also be formed at H, as far behind the mirror AB as F is before it. An image of H will again be formed in CD; and thus will be formed an indefinite series of images, all situated on the straight line EF.

If an object be placed between two plane mirrors inclined to each other, the images formed will lie in the circumference of a circle whose centre is the intersection of the two mirrors. If the mirrors are inclined to each other 90°, they will present three images of the object; if the angle be 60°, they will present five images, which, with the object, will all be situated on the circumference of a circle.

410. The *Kaleidoscope* depends upon this principle. Two plates of common looking-glass are fixed in a tube, so as to form an angle of 60° with each other. Semi-transparent objects of various colors are placed before them, and confined between two parallel plates of glass. Thus each colored fragment will have five images, which, with the object itself, will be placed at the six angles of a regular hexagon, whose centre will be the point of intersection of the mirrors. Thus the images of all the fragments are symmetrically arranged, however irregular may be their position between the mirrors. Three mirrors are commonly combined, furnishing three angles of 60° each, about each of which is formed a figure, which, on account of its symmetry, is always pleasing to the eye. This instrument was invented in 1814 by Sir David Brewster.

411. *Reflection of light from a curved surface.*

In order that *all the rays* which diverge from one point and fall upon a reflecting surface may be collected in another point, the surface must have *such a curvature* that lines drawn from the two points in question to any point on the surface shall make *equal angles* with the surface. Such a surface is *an ellipsoid*, which is formed by the revolution of an ellipse about its major axis, the two fixed points being its foci. It is not necessary that the surface should form an entire ellipsoid. *Any portion of it* will reflect rays which diverge from one focus, so as to make them converge to the other focus.

If rays proceeding from a very distant object, as the sun, fall

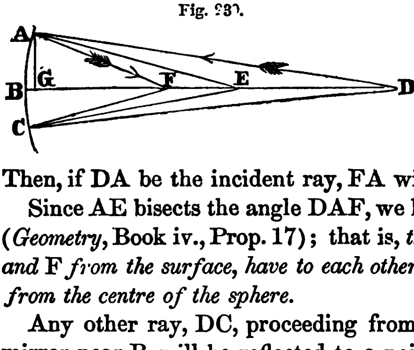
upon *a parabolic reflector*, in directions parallel to its axis, they will be made to converge to its focus; or if a luminous point be placed in the focus of such a reflector, its rays will be reflected in directions parallel to the axis.

412. *Spherical reflectors.* If the surface of the mirror form *a small portion of a sphere*, its deviation from the parabolic figure will be scarcely appreciable, and hence *parallel rays incident upon a spherical surface of small extent, will be made to converge nearly to one point.*

Since all the radii of a sphere are perpendicular to its surface, rays which proceed from the centre of a spherical mirror, and fall upon its surface, will be reflected back to the centre. The position of the focus of the reflected rays changes with the position of the radiant or luminous object.

Let D be a luminous point placed before the mirror ABC, supposed to be a small portion of a spherical surface whose centre is E. Draw the line AF, making the angle EAF equal to the angle EAD.

Fig. 231.



Then, if DA be the incident ray, FA will be the reflected ray.

Since AE bisects the angle DAF, we have DA : FA :: DE : FE (*Geometry*, Book iv., Prop. 17); that is, *the distances of the points* D *and* F *from the surface, have to each other the ratio of their distances from the centre of the sphere.*

Any other ray, DC, proceeding from D, and falling upon the mirror near B, will be reflected to a point near F, because DC is nearly equal to DA, and FC to FA. Hence all the rays diverging from D, and falling upon the mirror, will be crowded together near F, and produce a bright light or focus. The point F is called *the focus conjugate to the focus* D.

Draw AG perpendicular to DB. Then, since

$$AFG = AEG + FAE,$$

and

$$ADG = AEG - DAE,$$

adding these equations together (since $DAE = FAE$), we find

$$ADG + AFG = 2\ AEG.$$

But, since the mirror is supposed to be a small portion of a spherical surface, these angles will be nearly equal to their sines,

and hence, $\sin. \mathrm{ADG} + \sin. \mathrm{AFG} = 2 \sin. \mathrm{AEG}.$

Also,
$$\sin. \mathrm{ADG} = \frac{\mathrm{AG}}{\mathrm{AD}},$$
$$\sin. \mathrm{AFG} = \frac{\mathrm{AG}}{\mathrm{AF}},$$
$$\sin. \mathrm{AEG} = \frac{\mathrm{AG}}{\mathrm{AE}}.$$

Hence,
$$\frac{\mathrm{AG}}{\mathrm{AD}} + \frac{\mathrm{AG}}{\mathrm{AF}} = \frac{2\mathrm{AG}}{\mathrm{AE}},$$

or
$$\frac{1}{\mathrm{AD}} + \frac{1}{\mathrm{AF}} = \frac{2}{\mathrm{AE}}.$$

If we put $\mathrm{D} = \mathrm{AD}$; $d = \mathrm{AF}$; $r = \mathrm{AE}$, we shall obtain
$$\frac{1}{\mathrm{D}} + \frac{1}{d} = \frac{2}{r}.$$

In this equation we have three variable quantities, any two of which being given, the third can easily be found.

Example 1. The radius of a concave mirror is 10 inches, and light falls upon it diverging from a point 14 inches in front of the mirror. Find the distance of the conjugate focus from the mirror.

Here we have
$$\frac{1}{14} + \frac{1}{d} = \frac{2}{10},$$

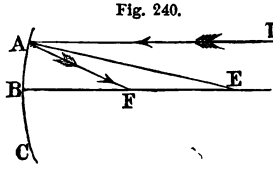
from which we find $d = 7.77$ inches.

Example 2. If a pencil of light diverge from a point 34 inches from a concave mirror of 2 feet radius, find the conjugate focus.

Ans. $d = 18.54$ inches.

413. *Parallel rays incident upon a concave spherical mirror, and near its axis, are reflected to a focus equidistant from the surface and centre of the mirror.* Let DA be a ray of light falling upon the spherical mirror ABC in the direction of its axis, EB, and let E be the centre of curvature. Make the angle FAE equal to the angle DAE; the ray DA will be reflected in the direction AF. Then, because the angle FAE = DAE, which equals the alternate angle AEF, therefore FAE = FEA, and FA = FE. When the point A is near the axis BE, AF will be sensibly equal to BF; that is, BF will be equal to FE. The point F, which is the focus for parallel rays, is called *the principal focus.*

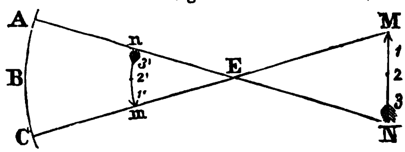
Fig. 240.



The focal length of a mirror is the distance of the principal focus from the mirror. Hence *the focal length of a mirror is equal to half the radius of curvature.*

414. *If a distant object be placed before a concave mirror, an image will be formed between its centre and surface.*

Fig. 241.



Let ABC be a concave mirror, E its centre, and MN an object placed at such a distance that the rays falling on AC may be regarded as parallel. The rays which diverge from M, and fall upon ABC, will all be collected in *m*, midway between C and E. Also, all the rays which diverge from N, and fall upon the mirror, will be collected in *n*, midway between A and E. So, also, the rays proceeding from the points 1, 2, 3, etc., will converge after reflection to the corresponding points 1′, 2′, 3′, etc. Thus *mn* will be an image of the object MN, and each point of the object will have its corresponding point in the image. *This image is inverted*, for the rays proceeding from the top of the object go to form the bottom of the image, and those from the bottom of the object go to form the top of the image.

415. *Size of the image.* Since M*m*, N*n*, are straight lines, we have MN : *mn* :: ME : *m*E; that is, *the diameter of the object* : *the diameter of the image* :: *the distance of the object from the centre of the mirror* : *the distance of the image from the centre.*

As the object approaches the mirror, its image recedes from the mirror, and vice versa. When the radiant is beyond the centre, the focus of reflected rays will be between the centre and principal focus; but when the radiant is between the centre and the principal focus, the focus of reflected rays will be beyond the centre.

Since the diameters of the object and its image are as their distances from the centre of the mirror, *the size of the image is independent of the area of the mirror.* An increase in the size of the mirror increases *the brightness* of the image, but does not increase its *dimensions.*

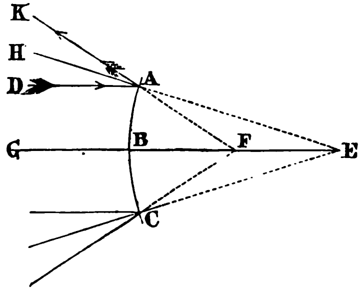
Example. The flame of a candle, measuring two inches in height, is placed in front of a concave mirror of 3 feet radius at

a distance of 10 feet. Find the distance and magnitude of the inverted image.

Ans. Distance, 21.17 inches;
Magnitude, 0.353 inch.

416. *Parallel rays incident upon a convex mirror are made to diverge as from a point behind the mirror.* Let ABC be a convex mirror whose centre is E, and let DA, GB, be parallel rays falling upon it. Produce AE to H, and make the angle HAK=HAD. Then, since the angle of reflection is always equal to the angle of incidence, the ray DA will be reflected in the direction AK, as if it proceeded from the point F. Also, the angles FAE, FEA, are equal to each other; therefore, FA=FE; and, if the mirror be small, FE will be sensibly equal to BF; that is, *the focus for parallel rays is at the middle point of the radius of curvature.*

Fig. 242.



The point F is not a point where the reflected rays actually unite, but where they would unite if they were continued backward from the surface of the mirror. Such a focus is called *an imaginary focus.*

In order to find by experiment the principal focus of a convex mirror, we may cover it with a screen having two small apertures distant from each other one inch. Let the reflected rays be received upon a screen placed at such a distance that the images of the two holes shall be two inches apart. The imaginary focus will then be as far behind the mirror as the screen is in front of it.

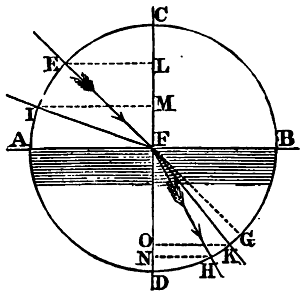
Diverging rays incident upon a convex mirror are made to diverge more than before reflection.

SECTION III.

REFRACTION OF LIGHT.

417. When a ray of light passes out of one medium into another of a different density, it changes its direction at the point which separates the two media. This phenomenon is called *refraction.*

Fig. 243.



Let AB be the surface which separates the two media; let EF be the incident ray, and let FH be the course of the ray after it enters the second medium. Draw CFD perpendicular to the surface AB. EFC is called *the angle of incidence,* and DFH *the angle of refraction.* If a straight rod be plunged obliquely in water, it *will appear to be broken* at the point where it meets the surface, the part immersed forming an angle with the part not immersed.

418. *Laws of refraction.* The following laws of refraction have been established by experiment:

1st. *The angles of incidence and refraction are in the same plane perpendicular to the refracting surface.*

2d. *The sine of the angle of incidence has to the sine of the angle of refraction, always the same ratio for the same medium.*

The ray EF, instead of proceeding in the straight line EFG, is bent at F in the direction FH. In like manner, another ray, IF, incident upon the same point F, is bent into the line FK. With F as a centre, describe a circle, ACBD, and perpendicular to CD draw EL, IM, HN, KO. Then it is found that whatever is the angle of incidence, EL : IM :: HN : KO.

419. If I represents the angle of incidence, and R the angle of refraction, then sin. I$=$sin. R$\times$*a constant quantity.* In the case of water, sin. I$=\frac{4}{3}$ sin. R. The constant $\frac{4}{3}$ is called the *index of refraction* for water. Each medium has its own index of refraction. The index of refraction for crown glass is about 1.5,

and for diamond about 2.5. Diamond has the greatest refracting power of all known substances, with but one or two exceptions.

Example 1. If a ray of light be incident upon water at an angle of 60°, find the angle of refraction.

By the second law of refraction we have the proportion

$$4:3::\sin. 60^\circ:\sin. r,$$

r denoting the angle of refraction. Hence,

$$r=40^\circ\ 30'.$$

Example 2. If a ray of light be incident upon crown glass at an angle of 60°, find the angle of refraction.

Ans. $r=35^\circ\ 16'$.

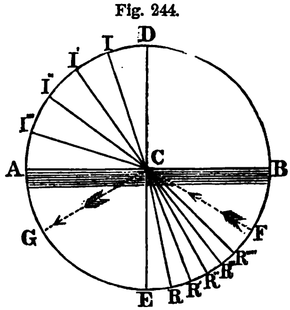
Example 3. If a ray of light be incident upon diamond at an angle of 60°, find the angle of refraction.

Ans. $r=$

When light passes from a rarer to a denser medium, the refraction is *toward the perpendicular* to the refracting surface. In passing from a denser into a rarer medium, the refraction is *f om the perpendicular* to the refracting surface. Thus, if a ray of light from H strike the refracting surface at F, it will proceed in the direction FE; that is, the directions of the incident and refracted rays passing between the two media are *interchangeable.*

420. *In passing from a rarer into a denser medium, the angle of refraction has a limit of magnitude which it can not exceed.*

Fig. 244.



Let AB represent the surface which separates the two media—for example, air and water. The incident ray IC will be refracted into the direction CR, which is nearer to the perpendicular DE. The ray I′C is refracted into the direction CR′; I″C into CR″; I‴C into CR‴, etc. In each case the sine of the angle of incidence is $\frac{4}{3}$ of the sine of the angle of refraction. As the incident ray approaches to coincidence with AC, the refracted ray approaches the position CR⁗. Thus light entering the water at C, from whatever direction it may come, can not reach any point between R⁗ and B.

If a ray of light proceed from any point, F, between B and R'''', to the point C, it can not pass out of the water, but will be *totally reflected* from the surface of the water in the direction CG.

This result may be exhibited in the following manner. Take a glass vessel filled with water, and introduce into it any convenient object, as a silver spoon. An eye placed below the level of the water may see a brilliant image of the spoon reflected from the under surface of the water.

421. The angle of total reflection may be found in the following manner. If we represent the index of refraction by m, we shall have, by Art. 419,

$$\sin. I = m \sin. R.$$

Total reflection begins when the angle of refraction has attained its greatest possible value. The angle of refraction will have its greatest value when $I = 90^\circ$, or $\sin. 90^\circ = 1$. Hence,

$$1 = m \sin. R;$$

or, $$\sin. R = \frac{1}{m}.$$

Example 1. Find the angle of total reflection of water, the refractive index of which is equal to $\frac{4}{3}$.

Here $$\frac{4}{3} \sin. R = 1,$$

and $$\sin. R = \frac{3}{4}.$$

Therefore, $R = 48^\circ\ 35'$.

Example 2. Find the angle of total reflection of crown glass.

Ans. $41^\circ\ 48'$.

Example 3. Find the angle of total reflection of diamond.

Ans.

When light is transmitted through a medium bounded by plane and parallel surfaces, the incident and emergent rays are parallel, since the deviation of a ray on emerging from the glass is the same as it was on entering the glass, but in a contrary direction.

422. *Refraction by prisms. A prism is a transparent medium having two plane surfaces not parallel to each other.* It may be formed of glass, water, or any transparent substance. Let ABC be a prism, of which AC is the base, and B the refracting angle.

Fig. 245.

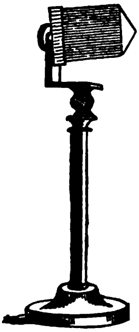
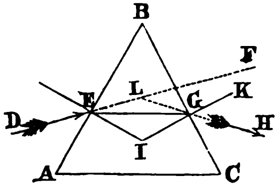


Fig. 246.

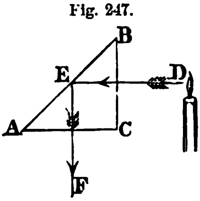


Let a ray of light, DE, fall upon the face AB obliquely. Instead of passing on in the direction DEF, it will be deviated *toward* the perpendicular EI, and will proceed in the direction EG. On emerging from the prism, it will be refracted *from* the perpendicular GK, and will proceed in the direction GH. The total deviation of the ray produced by the two refractions is HLF, and this deviation is always *toward* the base of the prism.

This deviation will be *least* when the incident and emergent rays make *equal angles* with the sides of the prism.

A right angled isosceles prism of glass is often used for a reflector. Let ABC be a section of such a prism. A ray, DE, falling perpendicularly upon the surface, BC, will enter the prism without refraction, and will meet the surface AB at an angle of 45°. Now, since the limit of transmission for glass is 42°, this ray must suffer total reflection, and will proceed in the direction EF, which is at right angles with the original direction DE. Such a reflector is generally adapted to the eye-piece of a telescope, for changing the direction of the rays of light.

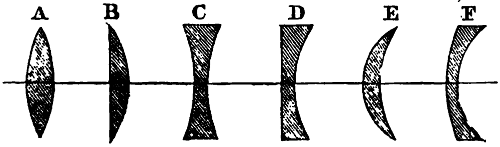
Fig. 247.



423. *Refraction by lenses.* A *lens* is a refracting medium included between two curved surfaces, or between a curved surface and a plane surface.

Lenses are commonly made of glass, and they are generally bounded by spherical surfaces. There are six varieties of lenses.

Fig. 248.

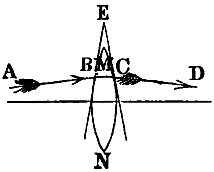


A *double convex* lens, A, is formed by two segments of a sphere placed base to base.

A *plano-convex* lens, B, is simply a segment of a sphere. A *double concave* lens, C, is bounded by two concave spherical surfaces. A *plano-concave* lens, D, is a lens, one of whose surfaces is plane and the other concave. A *meniscus*, E, is a lens, one of whose surfaces is convex and the other concave, but the convexity is greater than the concavity. A *concavo-convex* lens, F, is a lens, one of whose surfaces is convex and the other concave, but the concavity is greater than the convexity. The *axis* of a lens is the line which passes through the centres of its two spherical surfaces.

424. *A ray of light passing through a convex lens, is deviated toward the axis of the lens.* Let ABCD be a ray of light passing through the convex lens MN. Draw two planes touching the lens at the points of incidence and emergence, B and C. These planes form a prism whose angle is at E. The path of the ray of light will be the same as that of a ray through this prism, and therefore the ray will be bent *from the angle* E, that is, *toward the axis of the lens.*

Fig. 249.

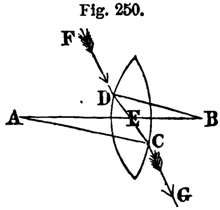


A convex lens may be regarded as an assemblage of prisms of different refracting angles, with their bases all turned toward the centre. Hence, when parallel rays fall on a convex lens, they are made to incline toward the axis, and the curvature may be so chosen that all parallel rays shall be made to converge to the same focus. This may be effected with a meniscus, whose convex surface is part of an ellipsoid, and whose concave surface is spherical; but a lens with both surfaces spherical has sensibly the same property, provided the diameter of the lens is small in comparison with the radius of curvature.

The focus for parallel rays is called *the principal focus.*

425. *In every lens there is a certain point, called the optic centre, through which rays, in passing, experience no deviation;* that is, the incident and emergent rays are parallel. Let A and B be the centres of curvature of the two surfaces of the lens. Draw any two parallel radii, AC, BD, and join DC. The point E, where this line intersects the

Fig. 250.

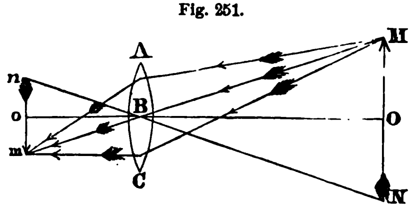


axis AB, is called the optic centre, and in the same lens this point is invariable. For, since the triangles ACE, BDE, are similar, we have $$AC : BD :: AE : BE.$$
Hence, $$AC + BD : AC :: AE + BE : AE.$$

But the first three terms of this proportion are invariable; hence the last term, AE, is invariable. Now, since AC and BD are parallel, the tangent lines at the points D and C are parallel to each other. Hence, if a ray of light, FD, fall upon the surface of the lens at D at such an angle as, after refraction, to take the direction DC, it will emerge in a direction CG, parallel to FD.

426. *Rays of light proceeding from an object which is farther from a convex lens than its principal focus, are made to converge to corresponding points on the other side of the lens, and form an image.*

Fig. 251.



Let ABC be a convex lens, and let MON be an object placed beyond the principal focus. Every point in the object sends forth rays in all directions, part of which fall upon the lens ABC. The rays which proceed from M are all made to converge to a point, *m*, on the other side of the lens. The rays from N are all made to converge to *n*, and the rays from O converge to *o*. Thus every point in the object has its corresponding point in the image, and the image becomes an exact copy of the object.

Since the rays from the top of the object go to form the bottom of the image, *the image is inverted with respect to the object.*

Also, since M*m*, N*n*, are straight lines, we have the proportion
$$MN : mn :: OB : oB;$$
that is, *the diameter of the object* : *that of its image* :: *the distance of the object from the lens* : *the distance of the image from the lens.*

427. *The size of the image* is therefore independent of the area of the lens. If we cover up a portion of the lens, the size of the image remains unchanged, but the brightness of the image will be diminished.

If we bring the object nearer to the lens, the image will recede from it on the other side; since the rays, being more divergent,

are not so soon brought to a focus. We may therefore magnify the image to almost any extent, by bringing the radiant very near to the focus of parallel rays, so as to form the image at a great distance.

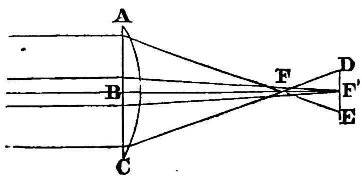
The image of any object may be regarded as a new object, and by placing a second lens behind it, a second image of the first will be formed; and this image will be inverted with respect to the first image; that is, *it will be erect* with respect to the object.

428. *A concave lens* may be regarded as an assemblage of prisms of different refracting angles, with their bases all turned *from the centre.* Hence, when parallel rays fall on a concave lens, they are made to *diverge* from the axis. If these rays be produced backward, they will meet in a point behind the lens. This point is called the focus. The focus for parallel rays is called *the principal focus.*

This point may be found by covering the lens with an opaque surface, having two small apertures distant from each other one inch. We then place behind the lens a screen, and vary its position until the distance between the two images is two inches. The focus will then be as far before the lens as the screen is behind it.

429. *Spherical aberration.* A lens may be constructed with one surface spherical and the other ellipsoidal, which shall cause parallel rays to converge accurately to a single point. A lens with both surfaces spherical possesses approximately the same property, if its surface be small in comparison with its curvature; but if the lens have considerable size, the rays will not all be brought to the same focus. Let ABC be a plano-convex lens, having its plane side turned toward the incident rays; and let the central part of the lens be covered with a disk of paper. The rays of the sun passing through the marginal portions of the lens will be made to converge to a focus at F. If now the disk be removed, and the lens be covered with a card, having a small aperture at its centre, an image of the sun will be formed at F′, more remote from the lens than

Fig. 252.



F. Hence we see that the rays which pass through the centre of the lens have their focus further from the lens than those which pass near the margin. If the entire surface of the lens be exposed, a portion of the incident rays will be made to converge to F, while other rays will converge to F′, and other rays to points intermediate between F and F′. The distance FF′ between the focus of the central rays and the focus of the marginal rays is called *the longitudinal aberration;* and the circle over which the rays are spread, whose diameter is DE, is called *the lateral aberration.* This aberration is called *spherical aberration,* because it results from the spherical figure of the lens. The amount of the spherical aberration varies with the thickness and curvature of the lens.

In a plano-convex lens, with its plane side turned to parallel rays, the spherical aberration is $4\frac{1}{2}$ times the thickness of the lens.

In a plano-convex lens, with its convex side turned toward parallel rays, the aberration is only $1\frac{17}{100}$ of its thickness.

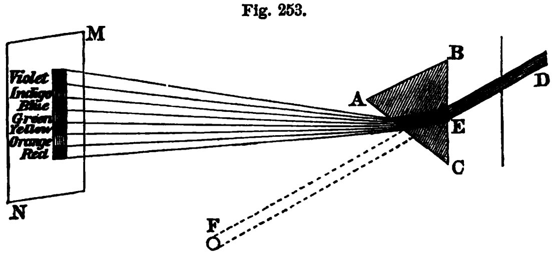
The lens which has *the least spherical aberration,* is a double convex one, the radii of whose surfaces are as 1 to 6. When the face whose radius is 1 is turned toward parallel rays, the aberration is only $1\frac{7}{100}$ of its thickness.

SECTION IV.

DECOMPOSITION OF LIGHT.

430. If a beam of solar light, DE, be admitted into a dark room through a small opening in a shutter, the rays will proceed in straight lines; and if a screen be placed at F, there will be

Fig. 253.



seen a small circular spot of light. But if a glass prism, ABC, be interposed in this beam of light, the rays, as stated in Art. 422, will be deviated toward the base of the prism.

All the rays are not, however, equally deviated, but they are *dispersed* into an oblong colored figure, called the prismatic spectrum, in which we distinguish seven different colors, *violet, indigo, blue, green, yellow, orange, red.* The violet rays are *most* refracted, the red *least.* These different colors do not all occupy equal portions of the spectrum. The violet occupies the largest portion, while the yellow and orange occupy the least.

If the several rays composing the spectrum be allowed to pass separately through a small aperture in a screen, and be received upon *another prism,* each ray will be refracted by the second prism, but it will undergo no further change of color.

431. *The seven colors of the spectrum all exist in white light.* This is shown by reuniting the colors of the spectrum, by which means white light is formed.

If the spectrum be received upon *a concave mirror,* the rays will be made to converge to its focus, and a white image will be formed. The same effect may be produced by passing the spectrum through *a double convex lens.*

If we pass the spectrum through *a second prism,* having the same refracting angle as the first, but with its base turned in the contrary direction, the second prism will neutralize the effect of the first, and the light which emerges will be white.

If a circular card be divided into seven sectors proportional in magnitude to the spaces occupied by the seven colors in the spectrum, and these sectors be painted with colors resembling the tints of the spectrum, then, upon revolving the card with great velocity, the card will present the appearance of *a grayish white.* If the colors of the spectrum could be exactly imitated, the card would appear perfectly white.

432. *All the different colored rays are necessary to produce white light.* If we intercept any portion of the rays of the spectrum, the image formed by the union of the other rays will be no longer white, but there will be a predominance of some one tint of the spectrum.

If we intercept the red end of the spectrum, the resulting image will exhibit a predominance of blue. If we intercept the violet

end of the spectrum, the resulting image will exhibit a predominance of red.

From the preceding experiments, we infer that *solar light is composed of rays differing from each other in refrangibility and color.* The least refrangible rays composing solar light are the red rays. But these red rays are not all equally refrangible, nor are they all precisely of the same color. So, also, the orange rays, the yellow rays, etc., are not all equally refrangible, nor are they all of precisely the same color.

433. *The permanent colors of bodies* are explained by supposing that, when a beam of white light is incident upon the surface of a body, it is decomposed, and that certain of the rays are reflected from it, while the remainder are absorbed. The rays which are absorbed vary with the substance of the body. An object of a green color reflects chiefly the green rays, and absorbs the rest. A white object reflects equally all the elementary rays, and a black object absorbs all, or nearly all.

A white object placed in the solar spectrum appears of the color of that part of the spectrum in which it is placed; because, being illumined by rays of only one color, it can only reflect rays of that color, and it must appear of the color of the rays which it reflects. The same is generally true of a colored object. Thus gold and silver placed in red light appear red; in green light they appear green, etc. If the natural color of an object is intense, its light will be most vivid when it is placed in that part of the spectrum which most nearly resembles the natural color of the body.

434. *Dispersion of light.* The difference between the refraction of the extreme rays of the spectrum is called *the dispersion* of the rays. Different media have different dispersive powers. Flint glass has a dispersive power about twice as great as crown glass, and nearly four times as great as water.

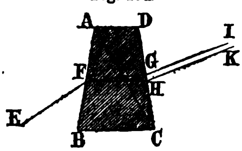
435. *Chromatic aberration of lenses.* As prisms decompose light, so must lenses. The violet rays, being most refracted, come to a focus first; and the red rays come to a focus at the greatest distance from the lens.

If the light of the sun be received upon a convex lens, since the differently colored rays converge to different foci, the lens will produce an infinite number of colored images formed at dif-

ferent distances. If these images be received upon a screen, the central portions will be superposed, forming white light; but the edges will exhibit colored fringes. Since the focus of the red rays is farthest from the lens, the red rays are on the outside of the converging pencil; and if a screen be placed a little nearer the lens than the focus, the image will be fringed with *red.* The violet rays form their focus first, and, after crossing, are found on the outside of the diverging pencil. Hence, if the screen be placed beyond the focus, the image will be fringed with *violet.* By interposing a small opaque object near the focus, we may intercept the central rays, and allow only the colored marginal rays to fall upon a distant screen, by which means these colors are rendered more conspicuous. The difference between the focal distances of the red and violet rays is called *chromatic aberration.*

436. *An achromatic prism* may be formed by combining two substances of different dispersive powers; as, for example, a prism, ABC, of crown glass, and a prism, ACD, of flint glass. If *the refracting angles of these two prisms are inversely as their dispersive powers,* and these prisms be superposed with their bases in contrary directions, a beam of light, EF, falling upon ABC, will be decomposed, but, after passing through ACD, the red and violet rays will emerge parallel to each other, and the beam GIHK will be sensibly white; nevertheless, the beam GI will not be parallel to EF.

Fig. 254.



437. *An achromatic lens.* The same principle is applicable to the construction of lenses. A lens nearly achromatic may be formed by combining a concave lens, B, of flint glass, with a convex lens, A, of crown glass; the two lenses having such curvatures that *their focal lengths shall be as their dispersive powers.* Such a lens will not be perfectly achromatic, because in the spectra formed with the two kinds of glass, the different colors do not fill exactly proportional spaces. When the radii of the lenses are so chosen as to bring the red and violet rays to the same focus, they will not bring the intermediate colors exactly to the same focus; yet the indistinctness resulting from this cause is so small as to occasion but little inconvenience. Achromatic lenses are now exclusively used in the construction of telescopes.

Fig. 255.

SECTION V.

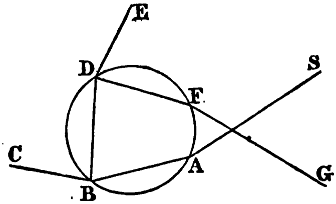
THE RAINBOW.

438. The rainbow consists of one or more circular arcs of prismatic colors, arranged in the order of the solar spectrum. For the production of a rainbow, it is necessary that the sun should shine during the fall of rain; and in order that the bow may be seen, the observer must be between the drops of rain and the sun, having his back to the latter. When two arches are visible, the inner one is the most brilliant, and its radius is about 42°, its centre being in the prolongation of the line drawn from the sun to the observer. This arch is called *the primary bow.* There is sometimes seen a second arch, less brilliant than the first, and exterior to it. This is called *the secondary bow.* It has the same centre as the former, and its radius is about 54°. In the primary bow the red band is on the *outside;* in the secondary bow it is on the *inside.*

If the sun is in the horizon, both bands are semicircles; if the observer be on the summit of a mountain, he may see more than a semicircle. Generally, less than a semicircle is seen.

439. *Cause of the bows.* These colors arise from the reflection and refraction of the sun's light by drops of rain. Drops of rain are sensibly spherical, and the sun's light, in passing through them, is decomposed, as in passing through a glass prism. Let ABD be a section of a drop of rain, and let SA be a beam of solar light falling upon the drop at A. A portion of this beam will enter the drop, and, after refraction, will take the direction AB. At B another portion will be refracted, and emerge into the air in the direction BC, while the remaining part of the beam will be reflected within the drop to D, where a portion will be refracted in the direction DE, and the remainder will be reflected to F. These refractions and reflections will be continued indefinitely; but the light which emerges after more

Fig. 256.

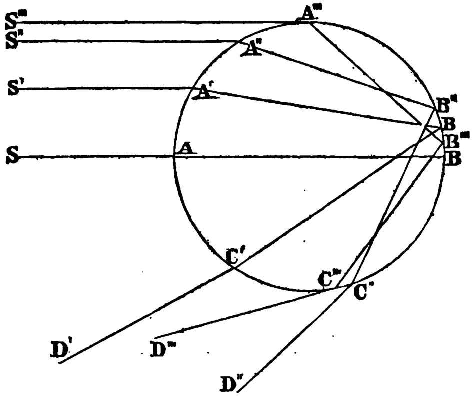


than two reflections is too faint to be seen except in very rare cases. Each refraction of the sun's light is accompanied with dispersion of the rays and the production of color.

440. *The primary bow.* The origin of the primary bow may be explained as follows:

Suppose a large number of parallel rays of light, SA, S′A′,

Fig. 257.



etc., to fall upon the drop ABC′. The ray SA, which passes through the centre, will be reflected from B back in the line AS, and suffer no deviation. The ray S′A′ will be refracted to B′, thence reflected to C′, and again refracted in the direction C′D′, making a small angle with the incident ray S′A′. The deviation of the emerging ray will become greater and greater as the incident ray recedes farther from the axis AB, until we reach a certain line, S″A″, for which the deviation is *the greatest* of all. A ray, S‴A‴, which falls upon the drop further from the axis, will emerge in the direction C‴D‴, experiencing a *less deviation* than S″A″. The greatest deviation for the red rays is about 42°. Hence we see that *the rays which emerge after one reflection from the interior of drops of rain, are all situated within a circle of 42° radius, whose centre is on the opposite side of the sun from the observer.*

If, then, the sun's light were entirely red, we should see opposite to the sun, when drops of rain are falling, a red circle of 42° radius; and it would be brighter at the edge than within the

edge, because most of the rays which are reflected from a drop suffer a deviation of nearly 42°. If the sun's light were violet, we should see opposite to the sun a violet circle of 40° radius, and brightest at the edge. If the sun's light were any other color, we should see opposite to the sun a circle of the same color, having a radius between 40° and 42°, and brightest at the edge. Consequently, since the sun's light is a mixture of all these colors, the effect is the same as if circles of all the prismatic colors, but decreasing in diameter from red to blue, were placed upon one another; that is, the inside is white, but the outside has brilliant rings of colors, of which the red is the exterior.

441. *The secondary bow.* In a similar manner, we shall find that *rays of the sun, after being twice reflected from the inner surface of drops of rain, may reach the eye from every portion of the heavens except a circle opposite to the sun, whose radius is about* 51°. That is, if the sun's light were red, we should have an illuminated red surface covering the entire heavens, with the exception of a circular space of 51° radius opposite to the sun. If the sun's light were violet, we should have a violet surface with a circular opening of 54° radius, which would be brightest at the edge, while the intermediate colors would furnish illumined surfaces with openings of intermediate size. And since the sun's light is a mixture of all these colors, the effect is the same as if these surfaces were superposed; that is, the inside ring is red, and the other colors follow the order of the spectrum.

Rainbows are sometimes formed at night from the light of the moon; yet they are much fainter than solar bows, and seldom attract notice.

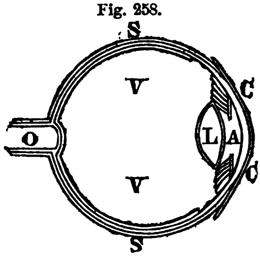
SECTION VI.

THE EYE.

442. The eye consists, first, of an apparatus for forming an image of external objects; second, a nervous system for transmitting the impressions to the brain; and, third, contrivances for protecting the other parts from injury. The eye has the form of a sphere about an inch in diameter; and its external coating

is lubricated by a fluid which is spread upon it by the action of the eyelid in winking.

Fig. 258.



The external coating, SS, consists of a tough membrane called *the sclerotic coat.* In the front part of this membrane is a circular opening, which is covered by a thin and perfectly transparent membrane, CC, called *the cornea.* Within the cornea is a small chamber, A, filled with a transparent liquid called *the aqueous humor.* This chamber is partially divided by a thin partition called *the iris,* in the centre of which is a circular aperture called *the pupil.* The color of the iris varies in different individuals. A little behind the iris, is suspended a transparent jelly-like substance, L, called *the crystalline lens,* having the form of a double convex lens of unequal radii, that of the anterior surface being the greater. The chamber behind the crystalline lens is filled with a transparent liquid, VV, called *the vitreous humor,* which is a little more viscid than the aqueous humor. Within the sclerotic coat is a second coat, called *the choroid.* The inner surface of this coat is covered with a slimy pigment of an intensely black color, by which the reflection of the light entering the eye is prevented. On this coat lies *the retina,* a very delicate reticulated membrane, consisting of exceedingly minute fibres branching from *the optic nerve,* O. This nerve, proceeding from the brain, enters the eye obliquely on the side next to the nose.

443. *Image formed on the retina.* When a luminous object is placed before the eye, the rays which fall upon the cornea pass through it; a portion are admitted by the pupil to the interior of the eye, are transmitted through the crystalline lens and the vitreous humor, and finally fall upon the retina. The aqueous humor, the crystalline lens, and the vitreous humor act as a system of converging lenses, by which the rays are brought to a focus near the retina, and an image of the luminous object is formed. This image must be *inverted* with respect to the object. That such is the fact may be rendered evident by taking the eyeball of an ox recently killed, and paring away the posterior coats until they become translucent. An inverted image of a candle

placed before the eye will then be seen through the retina, as upon a screen of ground glass.

The spherical aberration of the eye is corrected by the varying density of the crystalline lens, which, having the greatest refracting power near its centre, causes the central rays to converge to the same point as the marginal rays.

444. *Adaptation to different distances.* The eye possesses within certain limits the property of accommodating itself to objects at different distances. Thus most persons see objects distinctly not only at the distance of a few inches, but of several miles. It is supposed that this result is produced by a change in the curvature of the lenses of the eye, effected by muscular action.

There is, however, a limit of distance within which objects cease to be distinctly visible. For eyes which see distant objects clearly, this limit is about eight inches.

445. *Defects of vision.* If the curvature of the lenses of the eye be too great, the image of distant objects will be formed in front of the retina, and the distance of distinct vision is unusually small. Such eyes are said to be *short-sighted.*

When, from age or any other cause, the cornea or crystalline lens becomes flattened, the image is thrown farther back, and the distance of distinct vision is unusually great. Such eyes are said to be *long-sighted.*

Both the preceding defects may be remedied by interposing lenses of suitable curvature. If the lenses of the eye are too convex, the defect may be remedied by the use of a concave lens; if the lenses of the eye have too little convexity, the defect may be remedied by the use of a convex lens. Accordingly, aged persons are generally obliged to employ spectacles with convex glasses, while young persons are frequently obliged to employ spectacles with concave glasses.

446. *Duration of impressions on the retina.* The picture of a luminous object must remain on the retina a certain time in order to produce sensation; and the perception continues for a certain time after the object is removed from before the eye. Thus an ignited coal, when rapidly revolved, presents the appearance of a luminous ring. The duration of the impression increases with the intensity of the light. With ordinary illumination, the impression lasts about an eighth of a second; but in a dark

room the impression of a bright object may last one third of a second.

The thaumatrope, and other similar toys, are explained upon this principle. If we take a circular card about three inches in diameter, and on one side make a horizontal black stripe, and on the other side a vertical black stripe, upon making the card revolve rapidly we shall see a cross, because the impression produced upon the eye by the horizontal stripe is not obliterated when the vertical stripe becomes visible. If we paint a chariot on one side and a charioteer on the other, when the card is revolved with sufficient rapidity, the charioteer will appear in his proper place driving the chariot.

447. *Base of the optic nerve insensible.* The extremity of the optic nerve, from which proceed the minute filaments composing the retina, is entirely insensible to the action of light, and conveys no impression to the brain. This is proved by the following experiment. Place two small wafers before the eyes at a distance of 3½ inches from each other, and a distance of 12 inches from the eye. Closing the left eye, direct the right eye upon the left wafer, and the right wafer will not be seen, although objects immediately surrounding it on every side will be visible. If we close the right eye, and direct the left eye upon the right wafer, the left wafer will not be seen.

448. *Accidental colors.*

Two colors are called complementary to each other when together they form white light. Thus the color complementary to red is bluish green; the color complementary to orange is blue, and to green is a reddish violet. So, also, black and white are complementary to each other.

There are many cases in which a bright color, acting on the eye, excites the impression of the complementary color. If we close one eye, and look steadily through a blackened tube upon a colored surface brightly illumined, then, on turning the eye toward a white ground, we shall see a circular spot of the complementary color. This fact has been explained by supposing that, when the eye has been long fixed on one color (red, for example), its sensibility to that color is diminished; and when the eye is turned upon the white ground, the eye sees it of that color which arises from the blending of all the rays in white light except the red.

449. After the eye has been directed for a long time upon a colored surface placed upon a white ground, we perceive the margin of this surface to be fringed with the complementary color. So, also, if we look through a roll of colored paper upon a white wall, the wall appears of the complementary color. This fact has been explained by supposing that, when a part of the retina is excited by any color, not only is its sensibility to that color diminished, but the sensibility of the neighboring portion of the retina to the same color is also diminished, so that a white object appears tinged with the complementary color. The following experiment illustrates the same principle.

If we take two candles, and hold before one of them a piece of red glass, and remove the other to such a distance that the two shadows of any object formed upon a white screen may be equally dark, one of these shadows will be red and the other green. With a green glass a similar effect is produced.

450. *Colored figures in worsted.* If a small figure worked in red worsted upon a green ground, or worked in green upon a red ground, be moderately illumined by the light of a candle, and gently agitated, the figure appears in motion upon the canvas. If we carefully analyze this experiment, we shall find that, when a green figure or stripe is worked upon a red ground, and the card gently agitated, a shade of lighter green appears to spread over the whole figure, and overlap the surrounding red ground. A red stripe upon a green ground, when agitated, appears of a lighter red on each margin alternately, with a deep red wave oscillating back and forth at each motion of the card. This effect seems to be due to a partial and transient combination of the complementary colors. While the impression of the red color remains upon the retina, the same portion of the retina, in consequence of the motion of the card, receives a new impression of the surrounding green color. These two colors partially combine, producing, not white light, but a lighter shade of the primitive color.

SECTION VII.

OPTICAL INSTRUMENTS.

451. *Simple microscope.*

When we attempt to examine a very minute object with the naked eye at the ordinary distance of distinct vision, the image formed on the retina is too small to be clearly perceived; and if, in order to increase its apparent magnitude, we bring the object nearer the eye, the rays become too divergent to be brought to a focus on the retina, and the vision is indistinct. But by interposing between the eye and object a convex lens of suitable curvature, the eye is enabled to bring the rays to a focus on the retina, and the object appears distinct and magnified.

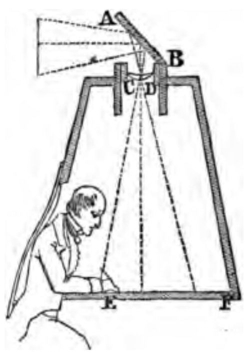
When an object is viewed by the naked eye, it can not, in most cases, be distinctly seen nearer than eight inches. But a convex lens placed at a distance from any object equal to its focal length, renders the rays from the object parallel, and the eye is then enabled to bring them to a focus upon the retina. Hence, *the magnifying power of the lens will be expressed by the ratio of the limit of distinct vision* (viz., 8 inches) *to the focal length of the lens.* If the focal length of the lens be one inch, the lens will magnify eight times; if it be $\frac{1}{10}$ of an inch, it will magnify eighty times. Lenses have been constructed of precious gems, whose focal length was only $\frac{1}{50}$ of an inch.

452. *The camera obscura.* If an object be placed before a convex lens at a distance greater than its principal focus, an image of the object will be formed on the other side of the lens. If a white screen be placed at the proper distance, the image will be depicted upon it, and the outline of the image may easily be traced with a pencil. An image may be formed by rays passing through a small aperture without a lens; but, in order to render the outline sharp, the aperture must be small, in which case the image will be very faint. By employing a lens, the image may be rendered both sharp and bright at the same time.

The camera obscura consists of a closed box, with a convex lens, CD, placed in the top, and having an opening at the side, covered by a dark curtain, to admit the artist. The light falls

horizontally on a plane mirror, AB, inclined at 45°, by which means it is thrown upon the lens, which forms an image of a distant object upon the screen EF. This screen generally consists of a sheet of white paper, on which the outline may be traced with a pencil.

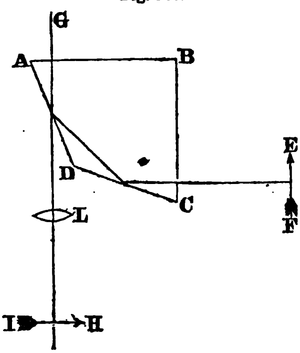
Fig. 259.



453. *The camera lucida.*

The camera lucida is an instrument used by artists for sketching landscapes, etc. It consists of a quadrilateral prism of glass, ABCD, right angled at B, and having the angle D equal to 135°. The remaining angles A and C are generally made equal to each other. The vertical face, BC, being directed toward any object, EF, which we desire to sketch, rays of light from the object enter the prism without refraction, and, being totally reflected from the surfaces CD and AD, emerge from the horizontal face AB without refraction, and, if the eye be placed at G, an image of the object will be seen at HI. If the eye be placed very near the edge of the prism, the picture of the object may be seen projected upon a sheet of paper, and the object may be sketched by a pencil, the point of which is visible by rays which pass outside of the edge of the prism.

Fig. 260.



Since the rays proceeding from the image are generally less divergent than those proceeding from the pencil, a convex lens, L, is placed above the paper, by which the divergence in both cases may be rendered equal, and both the image and pencil may be seen distinctly at the same time.

Colored glasses are generally placed before the face BC, to modify the light of the object to be sketched.

454. *The solar microscope.*

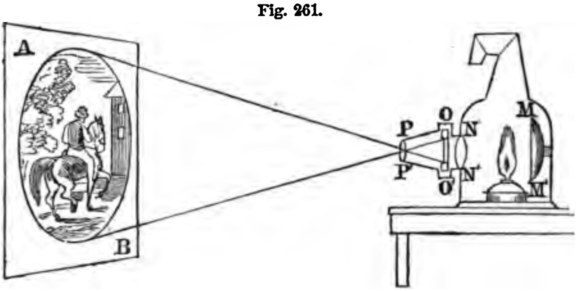
When a small but very bright object is placed a little beyond

the principal focus of a powerful lens, an image is formed, which may be received upon a screen placed at the proper distance. The brightness of the image will be diminished in the same proportion that it is magnified. In order, therefore, that the image may be bright enough to be distinctly seen, the object must be intensely illumined. In the solar microscope, this illumination is effected by reflecting the light of the sun into the tube of the instrument by means of a plane mirror, and receiving the rays upon a large convex lens called the *illuminating lens.* Near the focus of this lens is placed the object which is to be exhibited. Before this object is placed *a magnifying lens*, at a distance a little greater than its focal length; and *the diameter of the image will be to that of the object, as the distance of the image from the lens is to the distance of the object from the lens.* If the focal length of the lens be one tenth of an inch, and the image be formed at a distance of 30 feet, or 360 inches, the object will be magnified 3600 times in its linear dimensions, or more than ten million times in surface.

455. *The magic lantern.*

The magic lantern is an instrument by means of which pictures of objects, painted in transparent colors on glass, are magnified and received upon a screen. Fig. 261 represents the lantern provided with a silvered reflector, MM′, and a double convex lens,

Fig. 261.



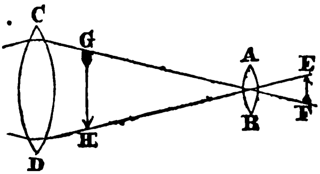
NN′, the reflector and lens being so placed that the light of a lamp occupies their common focus. By this arrangement a strong beam of parallel rays is thrown upon the glass slide inserted into the slit OO′. The figures upon this slide are painted with variously colored transparent gums, which allow the light

to pass freely through them. In front of the slide is placed a convex lens, PP′, at a little more than its focal length from OO′, and by means of this lens an inverted image of the picture on the slide is formed upon the screen AB. According to Art. 426, the diameter of the image formed upon the screen will exceed the diameter of the object painted upon the slide, in the ratio of their distances from PP′.

456. *The compound microscope.*

This instrument is designed to magnify very small objects, and render their structure distinctly visible. Its essential parts are two convex lenses; one, AB, called the *object-glass*, the other, CD, called the *eye-glass*. By means of the former, we produce a magnified and inverted image of a small object, EF, which should be placed at a distance from AB a little greater than its focal length; and this image, GH, is viewed by the eye-glass, CD, by which it is still further magnified. If the object be magnified by the first lens ten times, and if this image be viewed by a simple microscope whose magnifying power is 20, by this combination the object will be magnified 200 times.

Fig. 262.



The circular space visible through the microscope is called the *field of view*. It is generally limited by the rays which pass through the centre of the object-glass, and graze the margin of the eye-glass. By employing *a third lens*, the field of view may be increased. This lens is placed between the object-glass and eye-glass, and intercepts the extreme rays coming from the object, which otherwise would pass beyond the eye-glass.

Fig. 263.

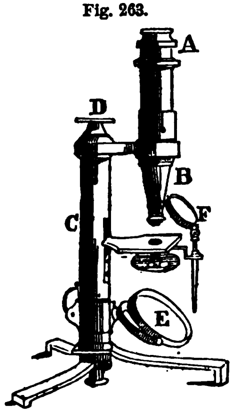


Fig. 263 represents the common form of the compound microscope. AB is the tube containing the lenses already described; C is the stand for supporting the tube; D is a screw by which the

tube can be elevated or depressed when the focal distance is to be adjusted; E is a mirror which reflects the light of a lamp or the sky upward to illumine the object; and F is a convex lens, which may be used in place of the mirror.

457. *The stereoscope.*

In viewing a solid object, especially if it be not very distant, each eye sees a different figure of it, some parts being hidden from one eye which are visible to the other; and it is by the union of these two pictures on the retina, that the impression of an object is produced. There is, therefore, a difference between the appearance presented by a solid body and that given by the best-drawn representation of it. To make the picture appear real, it should present two different aspects, one to each eye. This is accomplished by an instrument called the *stereoscope.* This consists of a small box for holding the pictures, and a pair of refracting eye-pieces for viewing the pictures. Two pictures of the same object are taken from points differing slightly in position, and related to each other in the same manner as the two eyes of an observer. Each eye-piece consists of a thin prism ground to a curved surface, so as to serve as a lens, and the two prisms, M, N, are placed with their refracting angles next each other. Rays from a picture at D, after passing through the prism M, reach the eye at A as if they came from C, while rays from a second picture of the same object at E, after passing through the prism N, reach the eye at B as if they came from C. Thus rays from both pictures reach the two eyes as if they came from a single picture midway between the two pictures.

Fig. 264.

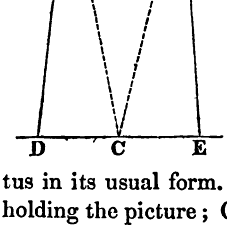
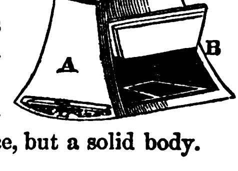


Fig. 265 represents the apparatus in its usual form. AB is the box for holding the picture; C and D are the eye-pieces, and a slide containing two views of the same building or landscape is inserted at E.

Fig. 265.

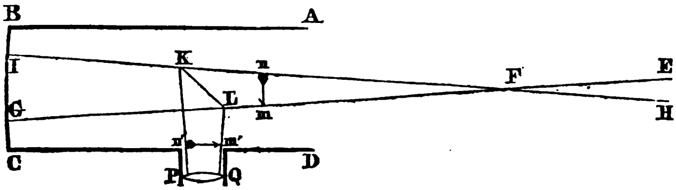


A statue or a building, when thus exhibited, appears no longer as a flat surface, but a solid body.

458. *Reflecting telescope.*

In a reflecting telescope, an image of a distant object is formed in the focus of a concave mirror, and this object is magnified by the eye-piece. There are several forms of the reflecting telescope, but those chiefly used at present are the Newtonian and the Herschelian. Let ABCD be a large tube, open at AD and closed

Fig. 266.



at BC, at which end is placed a concave mirror. Let there be a distant object from which the rays EG, HI, falling upon the mirror, form an image, *mn*, midway between the mirror and its centre of curvature, F. In the *Newtonian telescope*, a plane mirror, KL, inclined at an angle of 45° with the axis, is placed between the concave mirror and its principal focus, and the image of a distant object, which would otherwise be formed at *mn*, is deflected to *m'n'*. This image is viewed through an eye-glass, PQ, placed in an aperture in the side of the tube, at a distance from the image a little less than its own focal length.

459. *The magnifying power of the instrument* is determined in the following manner. Suppose the plane mirror KL to be omitted, and the image of a distant object to be formed at *mn*. Let EF be a ray proceeding from the top of the object, and passing through the centre of curvature of the mirror. Since it falls on the mirror perpendicularly to its surface, it will be reflected back in the direction GFE. Let HF be a ray proceeding from the bottom of the object, and passing through the centre of curvature of the mirror; it will be reflected back in the direction IFH. The rays IF and GF determine the diameter of the image *mn*, and if the eye were placed at F, the image would have the same apparent diameter as the object. But by means of a microscope like the eye-glass, we may view the image from a distance equal to the focal length of the eye-glass. Hence *the apparent diameter of the object seen through the telescope, will be to its diameter*

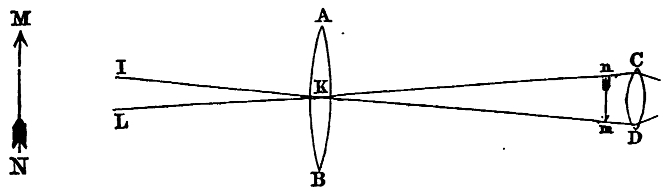
seen with the naked eye, in the ratio of the focal length of the concave mirror to that of the eye-piece. If the mirror have a focal length of 10 feet or 120 inches, and the focal distance of the eye-piece be $\frac{1}{10}$ of an inch, the telescope will magnify 1200 times.

460. In the *Herschelian telescope*, the image formed by the concave mirror is viewed directly by the eye-glass, without the interposition of a second mirror. In order that the head of the observer may intercept as little light as possible, the axis of the telescope is slightly inclined to the direction of the light, so that the image is formed near the side of the tube.

461. *Refracting telescope.*

In a refracting telescope, an image of a distant object is formed in the focus of an object-glass, and this image is magnified by the eye-piece. Let AB represent the object-glass, being a convex

Fig. 267.



lens of large aperture and considerable focal length; and let CD be the eye-glass, consisting of a convex lens of small aperture and short focal distance. Let MN be a distant object, from which the rays IK, LK, falling upon the object-glass, are made to converge to the focus, and form the image. This image is viewed by the eye-piece CD, which is placed at a distance from *mn* a little less than its focal length.

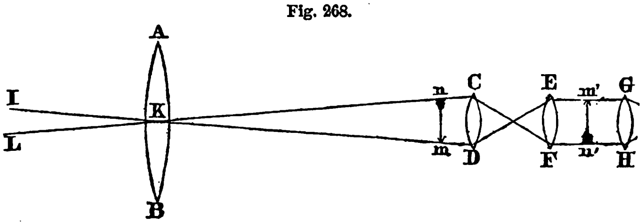
Since the rays which pass through the centre of the object-glass suffer no deviation, the vertical angles at K are equal; and if the eye were situated at the centre of the object-glass, it would see the object and its image under the same angle; or if the eye were placed at an equal distance from the image on the other side of it, the image would have the same apparent diameter as the object. But by means of the eye-glass we may view the image from a distance equal to the focal length of the eye-glass. Hence *the magnifying power of the telescope is the ratio of the focal distances of the object-glass and eye-glass.*

Example. The focal length of the object-glass of a telescope is 20 feet, and that of its eye-glass half an inch. What is its magnifying power? *Ans.* 480 times.

The brightness of the image depends upon the size of the object-glass; but the magnifying power is independent of the diameter of the object glass, except that a faint image will not bear a high magnifying power, because the light of the image is spread over so large a surface that the image is no longer distinctly visible.

462. *Terrestrial telescope.* The image seen in the astronomical telescope is *inverted* with respect to the object. For astronomical purposes this is unimportant, but for terrestrial objects it is a serious inconvenience. The ordinary terrestrial eye-piece contains two additional lenses for *rendering the image erect.* A second lens, placed at a suitable distance beyond the first image, would render the first image erect; but this lens must necessarily be very large, in order to receive all the rays which fall upon the object-glass. Two lenses of small size will accomplish the same object in a better manner. Let mn be the image of the object

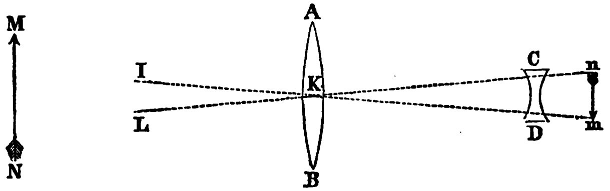
Fig. 268.



formed in the focus of the object-glass AB. A convex lens, CD, is placed before this image at a distance equal to its focal length, and the rays proceeding from mn, after passing through CD, emerge parallel. These rays are received by another convex lens, EF, of equal focal length, by which is formed the image $m'n'$, which is inverted with respect to mn, but erect with respect to the object. This image is magnified by the eye-glass GH in the usual manner.

463. *Galilean telescope.* The Galilean telescope consists of a convex object-glass and a concave eye-glass placed in front of the image, at a distance equal to its own focal length. The object-glass AB collects the rays of light as they proceed from the ob-

Fig. 269.



ject MN, and would form an image, *mn*, at a distance equal to its focal length; but the rays converging to this image are intercepted by the eye-glass CD, and, after refraction, emerge parallel, and enter the eye situated behind the lens. *The magnifying power is measured* by the ratio of the angles subtended by *mn* at the centres of AB and CD; that is, *by the ratio of the focal lengths of the object-glass and eye-glass.*

In the astronomical telescope, the distance between the object-glass and eye-glass is *the sum* of their focal lengths; in the Galilean telescope, the distance is *the difference* of their focal lengths. The Galilean telescope may therefore be made very *short,* and is best adapted to portable instruments like opera-glasses, etc.

SECTION VIII.

THEORIES OF LIGHT—INTERFERENCE AND DIFFRACTION.

464. Observations of the eclipses of Jupiter's satellites show that light is transmitted from one point of space to another, with a velocity of about 200,000 miles per second. This transmission may be supposed to be effected either by *the actual transfer of material particles* from the luminous body to the eye, or by the communication of motion by means of *the vibrations of an intervening medium.* This latter theory is called *the wave theory,* and is the one now generally adopted.

This theory assumes,

1st. That *an exceedingly rare and elastic medium,* or ether, as it is called, *fills all space,* even the intervals between the molecules of material bodies. This ether has inertia, but not gravity. In void space, the elasticity of the ether is supposed to be the same

in all directions. The same is supposed to be the case in uncrystallized matter; but in most crystals the elasticity is supposed to be different in different directions.

2d. The particles of a luminous body are in a state of *rapid vibration*, and possess the property of communicating similar vibrations to the molecules of the ether; and *these vibratory motions are propagated* throughout the ether in all directions.

3d. When these vibrations reach the retina, their action produces the sensation of light in a manner analogous to that in which the vibrations of the air affect our auditory nerves with the sensation of sound.

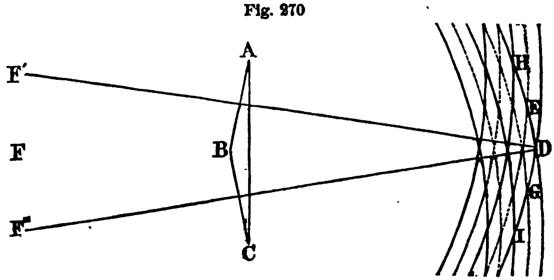
4th. *The color of the light is determined by the frequency of the vibrations*, and *its brightness by the amplitude of the vibrations.* The length of a wave of violet light is 17 millionths of an inch; the length of a wave of red light is 27 millionths of an inch.

465. *Interference of vibrations.* It follows from the wave theory that, if two molecules of ether be removed half the length of a wave from each other in the path of a ray of light, they will always be affected by equal but opposite velocities. The same is true of such particles as are removed $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, etc., of the length of a wave. Hence, when two similar systems of waves intersect each other at a very small angle, their effect is to double the intensity of the light when their paths are equal, or differ by an entire number of undulations; but they neutralize each other when the difference of their paths is equal to a half undulation, or any odd number of semi-undulations. *Two rays of light may thus*, under certain circumstances, *interfere with each other, and produce darkness.*

There are many modes of exhibiting these interferences. The following is one of the simplest.

466. *Experiment with obtuse prism.* Let the sun's light be admitted into a dark room through a convex lens of short focus. Let F (*Fig.* 270) be the focus of the lens, and let ABC be a prism with a very obtuse angle at B. The rays diverging from F, and falling on the surface AB, are refracted as if they proceeded from F′, while the rays proceeding from F, and falling upon BC, are refracted as if they proceeded from F″. Each of the points F′ and F″ may therefore be regarded as the centre of a system of waves which are propagated as if they proceeded from F′ and

Fig. 270



F″. With F′ as a centre, describe a series of black circular arcs, at intervals corresponding to the breadth of a luminous wave, and midway between these describe a series of dotted circular arcs. With F″ as a centre, describe a similar series of black and dotted arcs. All points situated upon either of the black arcs will be in the same phase of vibration, but the points situated upon a dotted arc will be in the contrary phase from points upon the black arcs. At the point D, two waves from F′ and F″ arrive in the same phase, and produce a double illumination. At E and G, two waves arrive in contrary phases, and therefore interfere with each other. At H and I, two waves arrive in the same phase, and produce a double illumination. If the experiment be tried with red light, and a screen be placed at D, we shall see at D a red band, at E and G black bands, at H and I red bands; that is, we shall have a series of red and black bands alternately. If the experiment be tried with violet light, we shall have a series of bands alternately violet and black, and the bands in violet light will be narrower than those in red light. The other colors of the spectrum will furnish a series of bright and dark bands, whose breadths are intermediate between those in red and violet light. When the experiment is tried with white light, the several systems of bands are formed simultaneously, and superposed upon each other. The superposition of all the colors of the spectrum at D produces a white band, but, as the red band is a little the broadest, the white band has a fringe of red on each side of it. On each side of this band, at E and G, succeeds a dark band. The violet of the next system of bands, at H and I, projects upon the inside, and the red projects upon the outside, so that we have a light band with an excess

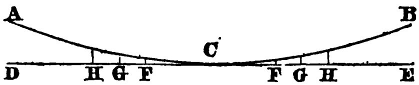
of violet on the inside, and of red on the outside. Beyond H and I, other colored bands are formed in a similar manner.

These phenomena, which are easily verified by experiment, are necessary consequences of the wave theory, and seem *inexplicable on the theory of emission*. This is therefore regarded as *a test experiment*, which decides in favor of the wave theory.

467. *Colors of thin plates.*

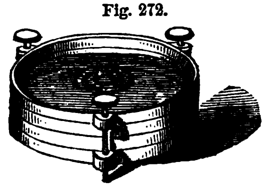
If a convex lens, ACB, of a very slight convexity, be laid upon a flat plate of glass, DE, we shall have a thin plate of air, whose thickness increases from the point of contact, C, and is the same at equal distances from that point.

Fig. 271.



Suppose a beam of red light to fall upon the surface DE perpendicularly to it. A portion of it will be reflected from the convex surface of the lens ACB, and another portion from the surface of the plate DE. These two systems of waves will intersect each other, and alternately increase or destroy each other's effect, according as their paths differ by a whole number of undulations, or by an odd number of semi-undulations. At a certain distance from C, as at F, the difference of the paths of the two beams of light will be equal to a half undulation, and the waves *interfere* with each other. At a greater distance from C, as at G, the difference of the paths is equal to one entire undulation, and the waves *conspire together*. At a still greater distance from C, as at H, the difference of the paths is equal to one and a half undulations, and the waves again *interfere* with each other; that is, we have alternately red and black rings surrounding the central point C. If violet light be employed, a similar system of rings will be produced, but their diameters will be less than in red light, and with the other colors of the spectrum rings will be formed of intermediate dimensions. If compound solar light be employed, there will be formed a series of rings produced by the superposition of all the systems of rings formed in red, yellow, green, etc., light.

Fig. 272.



468. *Fig.* 272 represents a convenient form of apparatus for exhibiting these results. A convex lens of very

small curvature is placed upon a plate of plane glass, and both are secured in a frame, so that they may be pressed together by means of screws. When this instrument is held before an open window, we may observe a series of *brilliant colored rings*, whose dimensions change with the slightest motion of the screws.

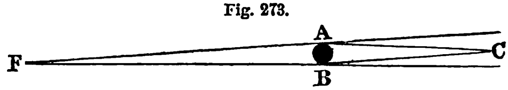
These rings were first carefully studied by Sir Isaac Newton, and are hence called *Newton's rings.* By measuring the diameters of the rings, and knowing the radius of curvature of the lens, Newton was able to compute the thickness of the plate of air in which each ring was formed, and hence we deduce *the length of a wave of light for each of the colors of the spectrum.*

Similar colors are observed whenever transparent substances are exhibited in sufficiently thin plates or laminæ, as in soap bubbles, in bubbles of glass blown to extreme tenuity, in oil thinly diffused over the surface of water, in the wings of insects, etc.

469. *Diffraction.*

Whenever light emanating from a luminous point, F, encounters an obstacle, AB, the waves diverge from this obstacle as from a new origin.

Fig. 273.



If F be the focus of a convex lens through which the sun's light is admitted into a dark room, and AB be a small opaque object interposed in the pencil, then a series of waves will diverge from A, and will spread into the geometrical shadow cast by AB. Another series of waves will diverge from B, and also spread into the geometrical shadow cast by AB. At the point C, equally distant from A and B, these two waves will arrive in the same phase, and will *re-enforce* each other, producing a bright point. At a little distance on each side of C, these waves will arrive in contrary phases, and *interfere* with each other, producing darkness. Thus *the centre of the shadow of a small opaque disk appears a bright point, and is surrounded by a dark ring.*

So, also, if a fine needle be interposed in the pencil, *the middle of the shadow will be marked by a white central line,* and colored fringes will be formed on both sides of the geometrical shadow.

470. Whenever an opaque body is interposed in a pencil of homogeneous light diverging from an exceedingly minute origin,

its shadow is bordered by a series of bands or fringes alternately bright and dark. The breadth of the fringes varies with the color of the light, being least in violet light, and increasing, in the order of the colors of the prismatic spectrum, to the red.

If we employ an opaque surface pierced with a very narrow aperture, the illuminated space on the screen will be much broader than the geometrical projection of the aperture, and the shadow will be bordered with fringes. *If the sides of the aperture form an acute angle, the shadow will be widest at the point corresponding to the vertex of the triangle.*

If the light be admitted through a small pin-hole in a metallic plate, the hole will appear surrounded by rings alternately bright and dark. If two small holes be employed, each will be surrounded by rings; and if these holes be near to each other, the rings will modify each other, producing very complicated figures.

If white light be employed in the preceding experiments, instead of bright and dark bands we shall have fringes showing the different colors of the solar spectrum.

All these phenomena are necessary consequences of the wave theory.

BOOK SEVENTH.

MAGNETISM.

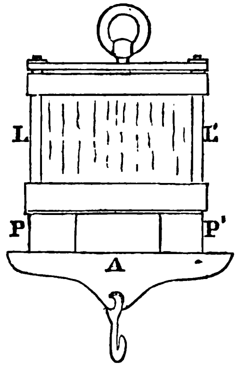
SECTION I.

GENERAL LAWS OF MAGNETISM.

471. *Definitions.* A *magnet* is a body which has the power of attracting iron in preference to other metals. The unknown cause of this attraction we designate by the term *magnetism.*

If we dip a magnet in iron filings, a considerable quantity of the filings will adhere to the magnet. Small nails, and even large pieces of iron, are attracted in the same manner.

Fig. 274.



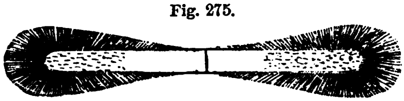
The *loadstone* is a natural magnet. It is an oxide of iron found in the earth in many parts of the world. A loadstone has been known to support more than 200 pounds.

An *artificial magnet* is a bar of iron or steel to which magnetism has been communicated. Magnets may have various forms. The most common forms are *the straight bar* and *the horse-shoe.*

Besides iron, two other metals, nickel and cobalt, exhibit magnetic properties in a feeble degree. Several other metals exhibit slight traces of magnetic action.

472. *Distribution of the magnetic force.* The attractive power which belongs to all magnets, whether natural or artificial, does not appear in equal strength upon every part of their surface. If a magnet be rolled in iron filings, the filings are chiefly collected about two opposite points, called the *poles.* Between the two poles is a line where the at-

Fig. 275.

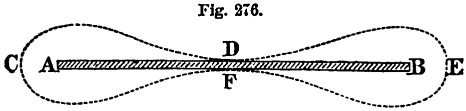


tractive power disappears, and no filings collect. This line is called the *neutral line.*

The intensity of the attraction of different parts of the magnet may be ascertained by bringing the magnet near to a small ball of iron suspended like a pendulum. If the neutral line of the magnet be brought near the ball, there will be no attraction, and the force of the attraction will be seen to increase as we recede either way from the neutral line.

The distribution of the attractive force over the surface of a magnet may be represented by a curved line, whose distance from the magnet is every where proportional to the intensity of the magnetic force. Let AB be a bar magnet; we may conceive a curved line, CDEF, to be drawn, so that its distance from the bar shall be every where proportional to the attractive force of the magnet.

Fig. 276.

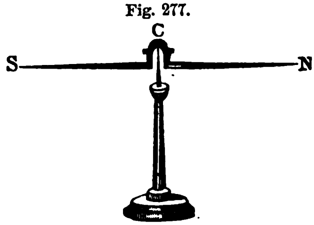


This curve touches the magnet at the points D and F, where the attraction is nothing, and recedes from the bar more and more toward A and B.

Iron attracts the magnet as much as the magnet attracts iron. If we suspend a magnet, and bring near to it a piece of iron, the magnet will be attracted by it.

473. *Poles distinguished.* If a magnet be supported upon a pivot, C, so as to be free to move in any direction, it will place itself nearly in the position of a north and south line. Hence one pole is called *the north pole,* and the other *the south pole.*

Fig. 277.



The attraction of a magnet is not obstructed by an interposed plate of glass, wood, paper, copper, water, or, indeed, any substance which does not contain iron. This attraction is readily exerted through a thick board, or even through the human body. If a magnet be placed in a glass tube, and the tube be hermetically sealed, the glass will not interfere in any degree with the attractive power of the magnet.

The magnet loses no power by *being touched.* It is not neces-

sary, therefore, that it should be *insulated*, like a conductor charged with electricity. See page 285.

474. *Magnetic attraction and repulsion.* If a magnet be supported so as to move freely, and the two poles of a second magnet be presented successively to the same pole of the first, we shall find that one pole will be attracted and the other repelled. The north pole of either magnet will repel the north pole of the other magnet, but attract its south pole. It is a general law of magnetic force, that *poles of the same name mutually repel*, while *those of different names mutually attract.*

475. *Induction.* If the extremity of a bar of soft iron be brought near to one of the poles of a magnet, this bar will itself immediately become magnetic, and will attract other iron like a permanent magnet. It will have two poles and a neutral line; that pole which is in contact with the magnet being of a contrary name from the pole which it touches. The second magnet will produce a third, the third will produce a fourth, and so on. Either pole of a magnet induces the opposite polarity in the nearest end of the iron bar, and the same polarity in the remote end. This process, by which magnetism is developed by magnetic action at a distance, is called *induction.* As soon as the first piece of iron is withdrawn from the magnet, it loses its magnetism almost instantly.

In this experiment, the magnet sustains *no loss* of power; consequently there is *no transfer* of magnetism from the magnet to the iron, but only the development of some principle previously existing in it.

476. *Hypothesis of two fluids.* These phenomena have been explained by supposing that all bodies susceptible of magnetism, such as iron and steel, are pervaded by two subtle fluids, called the *austral fluid* and the *boreal fluid.* The particles of either of these fluids repel each other, but attract the particles of the other fluid. So long as a body is not magnetic, the two fluids are in a state of combination, each particle of the one fluid being combined with a particle of the other, so that neither attraction nor repulsion is exhibited, since whatever could be attracted by a particle of one fluid is repelled by the particle of the other fluid which is combined with it. When a body is rendered magnetic, the two fluids are decomposed, the austral fluid being turned in

one direction, and the boreal in the other. That extremity toward which the boreal fluid is directed, is called the north pole of the magnet, and the other the south pole.

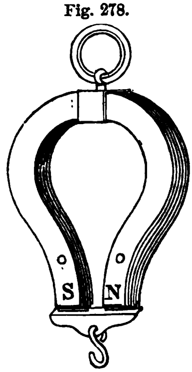
When similar poles of two magnets are presented to each other, they mutually repel, on account of the repulsion of the fluids which are present in them. When dissimilar poles are brought near each other, they mutually attract, because the fluids which are present in them have an attraction for each other.

Soft iron readily acquires magnetism, and as readily loses it. *Hardened steel* acquires magnetism slowly, but, having once acquired the magnetic power, it is not easily lost.

When iron filings are attracted by a magnet, it is because *each minute particle of iron* has its magnetism decomposed, and thus it *becomes a temporary magnet;* and since the south pole of a piece of iron is turned toward the north pole of the magnet, the two bodies attract each other. The same is true of each minute iron filing, and they all arrange themselves around the pole of the permanent magnet, as if each of them were a permanent magnet.

477. *Use of an armature.* A magnet *gains power* by communicating magnetism to other bodies. If we cautiously increase the load of a magnet from day to day, its power may be considerably augmented. Hence magnets should be provided with an *armature*, consisting of a piece of soft iron connecting the poles, and a moderate weight should be suspended from it. If the weight is made so great as to fall off, the power of the magnet is generally very much impaired.

Fig. 278.

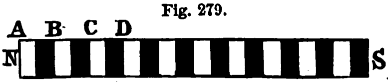


478. *A broken magnet.* It might be expected that, if a magnet were divided in the middle, two magnets would be produced, one having only a north pole, and the other only a south pole. Such, however, is not the case. If a permanent magnet be broken in the middle, two complete magnets will result, *each having a north and a south pole.* If these parts be again divided, other magnets will be formed, each having a north and a south pole. Whatever be the number of parts into which a magnet is divided, each part will be a complete magnet, having both a north and a south pole, as well as a neutral line.

If these several magnets be reunited in their original positions, they will form a single magnet with but one north pole and one south pole.

479. *Magnetic fluid not transferred.* Hence we conclude that, when a body is magnetized, there is no *transfer* of the magnetic fluids toward the extreme ends of the magnet. The boreal fluid does not pass wholly to one side of the neutral line, and the austral fluid wholly to the other side; for, if such were the case, when the magnet was divided, one part would have an excess of the austral fluid, and the other an excess of the boreal fluid. It seems probable that the decomposition of the magnetic fluids is confined to *the molecules* of the magnet, the boreal fluid passing to one side of the molecule, and the austral fluid to the other side. When a bar is not magnetic, the two fluids belonging to each molecule are combined, neither prevailing more on one side than the other. But when a bar is magnetized, the austral fluid of each molecule, as AB, CD, is turned toward the austral pole S, and the boreal fluid toward the boreal pole N, as represented in *Fig.* 279. This theory explains how a magnet may be broken into several fragments, and each portion remain a perfect magnet.

Fig. 279.



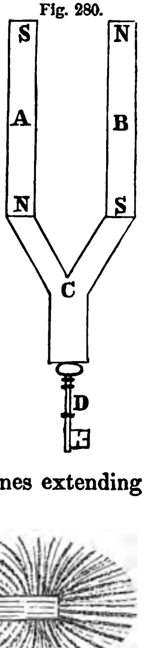
480. *Magnet with two north poles.* A permanent magnet may have two north poles or two south poles. If we place a steel bar, not magnetized, between two south poles of magnets, each end of the first bar will have a north pole, and there will be a south pole at the middle. This is, in effect, a method of uniting in the same bar two magnets with similar poles adjacent to each other.

If a long bar of unmagnetized steel be brought near to the pole of a strong magnet, a north pole, for example, its magnetism will be slowly decomposed; but it will require a sensible time for the decomposition to reach the end of the bar. Sometimes the north polarity never reaches the end of the bar, but stops at a nearer point, in which case a weaker south pole generally appears at some greater distance. This may be succeeded by another north pole, and so on for several alternations.

481. *Distribution of magnetism on soft iron.* Magnetism may be distributed upon a plate of soft iron in various ways. If the

north pole of a magnet be placed on the centre of a *round iron plate*, the plate will have a south pole at its centre, and every part of its circumference will have the properties of a weak north pole. If the plate have the form of a *star*, each of the points will be a north pole.

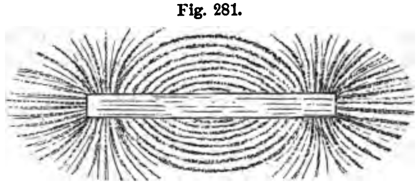
Fig. 280.



If we take a piece of soft iron, C, in the shape of the letter Y, and suspend it from the north pole of a magnet, A, by one of the branches of the fork, its lower end will become a north pole, and will attract another piece of iron, D, such as a key. But if we apply to the other branch of the fork the south pole of a second magnet, B, the key will immediately drop off. The reason is, that the magnet B tends to induce upon the lower end of the fork, a polarity contrary to that which is induced upon it by A, and thus the effect of A is neutralized.

482. *Magnetic curves.* If we place a sheet of paper over a magnetic bar laid flat upon a table, and having scattered some iron filings over it, tap gently upon the paper, so as to put the filings into agitation, they will arrange themselves in curved lines extending from one pole of the magnet to the other. These curves are called *magnetic curves.* They have the form of lines diverging from either pole; and the two poles are connected by lines of an oval shape. By combining the poles of magnets in various ways, a variety of magnetic curves may be exhibited.

Fig. 281.



These curves have been imagined to indicate the escape of some fluid or influence from the pole of the magnet. They are, however, the simple result of the attraction and repulsion of the two poles. Each iron filing becomes a temporary magnet, and takes up a determinate position, just as a permanent magnet, similarly situated, would do. The dissimilar poles of these particles attract each other, and thus the filings arrange themselves in lines diverging from either pole.

483. *How magnetism is impaired.* The strength of magnetism is impaired by *heat.* If a magnet, whether natural or artificial, be raised to a red heat, its magnetic power will be entirely expelled. When the magnet is allowed to cool, its magnetism does not return to it; but magnetism may be again communicated to it as to any unmagnetized bar.

The strength of a magnet is impaired by *rough treatment*, such as a fall upon the floor, hammering, rubbing, or grinding, or jerking off the armature. The power of a magnet may be increased by adding slightly to its load from day to day. Suppose a magnet can sustain a weight of four pounds. By adding daily a small weight, we may increase its power until it will support perhaps six or eight pounds; but if we load it so heavily that the armature falls off, the strength of the magnet will be so far impaired that it will no longer support more than about four pounds; and by repeatedly jerking off the armature, its power will be still further diminished. When the armature, therefore, is to be removed, it should be done by sliding it carefully up toward the neutral line.

484. *Is the earth a magnet?* A magnetic needle freely suspended uniformly turns toward the same point of the horizon; and if forced from this position, it will return to it after a series of oscillations. This property is observed in all parts of the world. There must, therefore, be a magnetic force, which acts at all points of the earth's surface, to give direction to the needle. We are hence naturally led to regard the earth as *a great magnet*, and as having one pole situated to the north of us, attracting the north pole of a needle in that direction.

If we suspend a magnetic needle by its centre of gravity, so that it may move freely either in a vertical or horizontal plane, the extremity which turns toward the north will incline below the horizon, making at New York an angle with the horizon of about 72°. Hence we conclude that if the earth be a great magnet, giving direction to the needle, its pole must be situated, not on the north horizon, but *almost vertically beneath us.*

485. *Inductive influence of the earth.* If the earth is really a magnet, or if there is a large magnet beneath the earth's surface, we should conclude that *the magnetism of soft iron might be decomposed by it,* in the same manner as is done by a bar magnet.

Such we find to be actually the case. If we hold a bar of soft iron, two or three feet long, in the direction which a magnetic needle assumes when freely suspended, its lower end immediately becomes a north pole, and its upper end a south pole, as is shown by bringing a small magnetic needle near each end of the bar. On inverting the bar, we find that its poles have immediately changed, the lower end being still a north pole, and the upper one a south pole. If we hold the bar horizontally, pointing east and west, no such effect takes place.

A similar but slightly diminished effect is produced on a bar of iron suspended in a vertical position; and iron rods which have remained long in a vertical position frequently acquire permanent magnetism. This is frequently observed in lightning-rods, as well as tongs, pokers, etc.

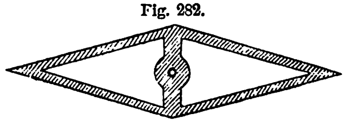
When a bar of iron is rendered magnetic by the influence of terrestrial magnetism, a stroke of a hammer will sometimes fix the magnetism, and the poles will not be reversed when the bar is inverted. But if we strike it several blows with the hammer when in the inverted position, its magnetism may be destroyed or its poles be reversed.

486. *The earth's action is simply a directive force.* The action exerted by the earth upon a magnetic needle is simply to give *direction* to the needle, for we find that the *weight* of a needle is not increased by its magnetism. Hence we conclude that the attraction of the earth for one pole of the needle, is exactly equal to its repulsion for the other pole.

If we place a magnetic needle upon a cork floating on water, it will soon adjust itself to the magnetic meridian; but it has no tendency to travel either toward the north or south.

487. *Best form of compass needles.* In a compass needle, it is desirable to combine *the greatest directive power with a given weight of needle.* Needles are frequently made in the form of a parallelopiped, but commonly they are somewhat pointed. Any appendages of irregular shape, such as are sometimes added for ornament, increase the friction upon the pivot, while they do not increase the directive power. Captain Kater, after a long series of experiments in

Fig. 282.



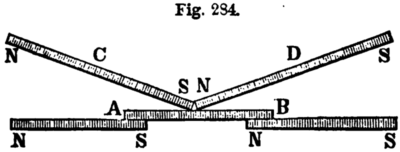
1821, concluded that the best form for a compass needle was the pierced rhombus, about five inches in length and two inches in width, as represented in *Fig.* 282.

This form, however, has not come into general use. A solid rhombus of the proportions represented in *Fig.* 283 is more generally preferred.

Fig. 283.

488. *Method of producing artificial magnets.* For producing artificial magnets, two principal methods have been employed. The first is called the method of *single touch*, and is practiced as follows: The bar, AB, which is to be magnetized, is laid upon the opposite poles, N and S, of two powerful magnets. The influence of the north pole N is to attract the austral fluid of the bar toward the end B, and to repel the boreal fluid toward the end A; and the effect of the south pole S is to repel the austral fluid toward the end B, and attract the boreal toward the end A. The bar AB will thus, in time, be converted into a magnet, having its north pole at A, and its south pole at B. The operation may be greatly accelerated by the following process. Let two bar magnets, C and D, be placed in contact with the bar to be magnetized, near its middle point, but without touching each other, and let them be inclined to the bar AB at angles of 30 degrees. Let the north pole of the magnet D be applied on the side of B, and the south pole of C be applied on the side of A. Taking the two bars, C and D, one in the right hand and the other in the left, let them be drawn in contrary directions along the bar AB from its middle to its extremities, and, being then raised from the bar, let them be again placed as before near its middle point, and drawn slowly toward its extremities. After the bar has been rubbed sufficiently on one side, it must be turned over, and the same operation repeated on the other side.

Fig. 284.



This method may be employed to magnetize compass needles, and bars whose thickness does not exceed an eighth of an inch.

489. *Method of double touch.* When the bars have considerable thickness, the method of *double touch* is more effectual. This method is as follows:

The magnets C and D are placed as before, except that they form an angle of 15 or 20 degrees with the bar AB. A small bit of wood is inserted between the magnets C and D, to prevent their coming in contact. The magnets C and D are then moved, together, first to one extremity of the bar B, and then back the whole length of the bar to A. They are again drawn together over the bar to B, and so backward and forward several times. After the bar has been rubbed sufficiently on one side, it must be turned over, and the same operations repeated on the other side. This process communicates a strong degree of magnetism.

SECTION II.

TERRESTRIAL MAGNETISM.

490. *Declination of the needle.* There are three elements of terrestrial magnetism to be considered, viz., *Declination*, *Dip*, and *Intensity*.

Although a magnetic needle, when freely suspended, generally points nearly north and south, it is found in almost all parts of the world that the north pole of the needle deviates a few degrees from the astronomical meridian. This deviation from the true meridian has been called the magnetic *declination*. The vertical plane which passes through the poles of the magnetic needle at any place, is called the *magnetic meridian* of that place; while the *astronomical meridian* is a vertical plane passing through the poles of the earth.

The declination of the needle is determined by placing a magnetic needle upon an astronomical meridian, and measuring its inclination to that meridian, which may be done with an azimuth compass or a theodolite.

The declination is said to be east or west, according as the north pole of the needle deviates to the east or west of the true meridian. The declination of the needle is very different at different places on the earth's surface. There are places where the declination is 10°, 20°, 30°, and even 90° west; and there are other places where the declination is 10°, 20°, 30°, and even 90° east.

491. *Line of no declination.* In order to represent all these observations conveniently upon a chart, we draw lines connecting all those places where the declination is the same. Such lines are called lines of *equal declination.* A line drawn through all those places where the needle points exactly north is called the line of *no declination.* This line surrounds the globe, and throughout most of its extent it does not deviate much from a great circle of the earth.

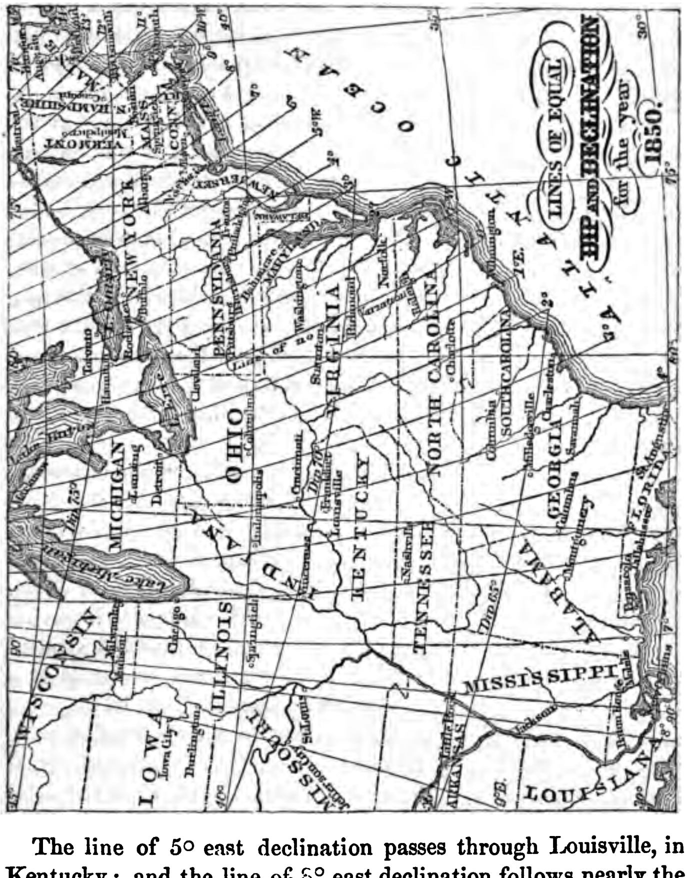
This line commences north of Hudson's Bay, in lat. 70° 5′ N., long. 96° 45′ W., and runs a few degrees east of south through Hudson's Bay and Lake Erie; entering the United States near the eastern line of Ohio, it passes through the centre of Virginia, and enters the Atlantic Ocean near Newbern, in North Carolina. Thence it veers somewhat more to the east, running a little eastward of the West India Islands, and, cutting off a portion of the eastern promontory of South America, it proceeds toward the south pole; but beyond lat. 70° we are unable to trace its progress for want of observations. In the eastern hemisphere, this line reappears south of New Holland, and runs northerly nearly through the centre of New Holland. Thence it veers abruptly to the west through about 50° of longitude, and sweeps in a great curve through the southern part of Hindostan, around Japan, into Siberia, and thence southwestward to the Caspian Sea. Here it turns to the northwest, and thence proceeds to the North Cape in lat. 71, whence we can no longer trace it for want of observations.

492. *Lines of equal declination.* The line of no declination divides the globe into two parts not very unequal. One of these parts we may call the Atlantic hemisphere, since it contains most of the Atlantic Ocean, and the other part we may call the Pacific hemisphere. Throughout the former hemisphere, the declination of the needle is every where westerly; throughout the latter, it is every where easterly; and the amount of the east or west declination generally increases with the distance of the point from the line of no declination. The declination in England is about 24° west, while in Greenland it ranges from 50° to 90° west.

The line of 5° west declination in the United States is nearly parallel with the line of no declination, and passes through Tren-

ton, in New Jersey; the line of 10° west declination passes through Boston, and the line of 15° west declination passes through Bangor, in Maine.

Fig. 285.



The line of 5° east declination passes through Louisville, in Kentucky; and the line of 8° east declination follows nearly the track of the Mississippi River.

493. *Change of declination.* These lines are all in motion westward; that is, the declination of the needle every where changes from one year to another. *In the Southern States the*

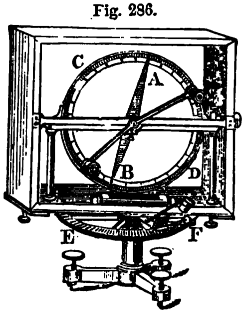
change is about 2′ annually; in the Middle and Western States, 4′; and in the Eastern States, 6′.

Besides the annual variation, the needle has a diurnal oscillation, amounting to about 15′ in summer, and 5′ in winter. From 8 A.M. to 1 P.M. the north end of the needle veers from east to west, and returns to its mean position by the next morning. This movement of the needle appears to be controlled by the course of the sun, and is probably the effect of solar heat.

494. *Magnetic meridians.* The lines of equal declination are extremely convenient for exhibiting the amount of the declination in every part of the world, but they are not well adapted to indicate the character of the force which gives direction to the needle. If we trace upon the globe a system of lines representing the actual direction of the magnetic needle at each station, the form of these lines bears a striking resemblance to the geographical meridians; but, instead of converging toward the geographical poles, the point of convergence in the northern hemisphere is in lat. 70°, long. 96° W., and that in the southern hemisphere is in lat. 76°, long. 153° E. These lines have been called *magnetic meridians.*

495. *Dip of the needle.* The *dipping needle* consists of a magnetic needle, AB, balanced on a horizontal axis, and moving in a vertical plane. Its inclination to the horizon is indicated by a vertical graduated circle, CD, the frame which supports it having a motion in azimuth round a vertical axis, and this motion is measured by a graduated horizontal circle, EF.

Fig. 286.



Preparatory to an observation with this instrument, the vertical circle must be made to coincide with the magnetic meridian; the angle which the needle, when thus adjusted, makes with a horizontal line, is called the *dip* of the needle.

496. *Magnetic equator.* At most places on the earth's surface, the dipping needle will not rest in a horizontal position, but assumes a position inclined to a horizontal line, one pole pointing downward and the other upward. This dip varies at different places from 0° to 90°, and observations to determine its amount

have been made in almost every part of the world. In order to represent all these observations conveniently upon a chart, we draw a line connecting all those places where the dip is the same. Such lines are called lines of *equal dip*. A line connecting all those places where the needle rests horizontally, is called the line of *no dip*, or the *magnetic equator*. This line exhibits numerous sinuosities in its course around the globe, but does not depart much from a great circle. It crosses the terrestrial equator near the western coast of Africa; attains its greatest southern latitude in South America, where it is 15° south of the geographical equator; crosses the equator again near the meridian of New Zealand, and attains a north latitude of 12° near the southern part of Hindostan.

497. *Magnetic poles.* As we travel northward from the magnetic equator, the north end of the needle inclines downward, and the dip continually increases at the rate of about 1° for 1° of latitude, until we reach the *north magnetic pole.* By magnetic pole we understand a place where the magnetic needle, freely suspended, *stands vertically.* Such a point was found by Captain Ross in 1832, north of Hudson's Bay, in lat. 70° 5′ N., long. 96° 45′ W.

As we travel southward from the magnetic equator, the south end of the needle inclines downward, and this dip continually increases until we reach the *south magnetic pole.* This point has never been visited by man; but a dip of 88⅔° has been observed, and the position of the south magnetic pole must be known very nearly. The most probable position of this point, as indicated by all our observations, is south of New Holland, in lat. 75° S., and long. 154° E.

498. *Lines of equal dip.* The lines of equal dip through the United States are situated as follows: The line of 60° dip passes nearly through New Orleans; the line of 65° dip passes through Milledgeville, Ga.; the line of 70° dip passes through Richmond, Va., Frankfort, Ky., and Astoria, in Oregon; the line of 75° dip passes through Portsmouth, N. H., and Rochester, N. Y.

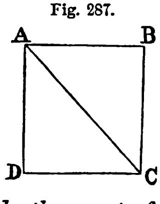
The dip of the needle is subject to continual change. Within the last hundred years, the dip at Paris has diminished 5°.

At present, the dip appears to be nearly stationary in the United States.

499. *Intensity of terrestrial magnetism.* The *intensity* of terrestrial magnetism may be measured by the number of vibrations made by a magnetic needle in a given time. If a dipping needle be drawn aside from its position of rest, the magnetism of the earth will bring it back to its first position, and its inertia will carry it beyond this point, whence will result a series of vibrations. The frequency of the vibrations will depend upon the strength of the magnetic influence. If we observe the number of vibrations made by the same needle in different parts of the earth in a given interval of time (for example, ten minutes), we may compare the intensities of terrestrial magnetism at these places; for the intensity varies as the square of the number of vibrations made in a given time.

500. *Total intensity deduced from horizontal intensity.* On account of the friction of the axis upon its supports, such observations made with a dipping needle are not very accurate, and it is better to observe the vibrations of a needle suspended by a slender fibre in a horizontal position. The force which causes the horizontal needle to vibrate is only a *portion* of the entire terrestrial magnetic force.

Fig. 287.



Let AB represent the horizontal intensity of the magnetic needle. Make the angle BAC equal to the dip of the needle, and from B draw BC perpendicular to AB; then AC will represent the total intensity of the magnetic force. But AC=AB×secant BAC; that is, *the total intensity is equal to the horizontal intensity multiplied by the secant of the dip.*

The needles which have generally been employed for measuring the magnetic intensity are about 4 inches long, and one or two tenths of an inch in diameter; sometimes in the form of cylinders, and sometimes of parallelopipeds.

In the vibrations of the needles there are frequently observed irregularities which have been ascribed to the resistance of the air. To obviate this evil, Professor Bache introduced the method of suspending the needle in a close glass vessel, from which the air has been mostly exhausted. Under these circumstances the vibrations of the needle are much more regular, and are continued for a longer time. Observers have generally been accus-

tomed to note the time which the needle requires to make 300 vibrations. Observations of this description have been made in numerous expeditions to almost every part of the globe.

501. *Observations of intensity.* In the year 1800, Humboldt found that a dipping needle, which in Paris made 245 vibrations in 10 minutes, when transported to Peru on the magnetic equator, made only 211 vibrations in the same time. Hence, calling the intensity at Peru 1, that at Paris is represented by $\left(\frac{245}{211}\right)^2$, or 1.348. The observations of magnetic intensity which have since been made, have all been referred to Humboldt's standard in Peru, although it is now known that there are large districts in which the magnetic intensity is feebler than it is in Peru. The least intensity any where found on the earth's surface is in South Africa, and is represented by 0.7. The greatest intensity hitherto discovered is 2.1; that is, *the greatest intensity is three times the least.*

502. *Lines of equal intensity.* In order to represent all the observations conveniently on a chart, we draw a line connecting all those places where the intensity is the same. Such lines are called lines of *equal magnetic intensity.* These lines in the equatorial regions run nearly east and west; but as we advance toward higher latitudes, the lines become more and more undulating. In the north polar regions, these lines arrange themselves around two centres, one of which is a little northwest of Lake Superior, in lat. 52° and long. 92°; the other is in the Arctic Ocean, north of Asia, in lat. 85° N., and long. 116° E. These points are called by Gauss *magnetic foci.* Moreover, the American focus is considerably stronger than the Asiatic. In the southern hemisphere, the lines of equal intensity arrange themselves around an elongated figure somewhat elliptical in form, whose centre is south of New Holland, in lat. 64° S., long. 137° E.

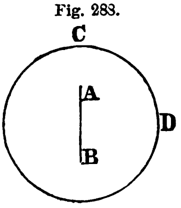
503. *How many magnetic poles are there?* A terrestrial magnetic pole is a point where the needle, freely suspended, stands *vertically.* Such a point has been found north of Hudson's Bay, and there is probably none other in the northern hemisphere. There is also a south magnetic pole, south of New Holland.

If there were but one focus of attraction in the northern hemi-

sphere, and if the magnetic influence were distributed symmetrically about that focus, we should expect the needle to stand vertically where the attraction was strongest; but when there are two foci, the needle can not stand vertically over either, because it is at the same time attracted not only by the nearer, but also by the remoter focus. It must therefore be at some point between the two foci that the needle stands vertically, and it must be a little nearer to the strongest centre, which is the American. These conclusions of theory accord with observation.

504. *Cause of the earth's magnetism.* If we attempt to account for the phenomena of terrestrial magnetism by the supposition of a large permanent magnet within the earth, its poles can not be supposed to be *near* the earth's surface, for then the intensity of the magnetism over the poles would be much greater than it now is. The supposition of a permanent magnet, AB, within the earth, about 4000 miles long, and whose poles are therefore 2000 miles beneath the earth's surface, would account in a general way for the phenomena in North America; for the distances AC and AD would be as 2000 to 4500; and the intensities of the attraction of the pole A at those places would be inversely as the squares of these numbers. The effect of the pole B may be found in a similar manner, and the resulting intensity at C would be to that at D nearly as 3 to 1, which corresponds with observation. But to account for the phenomena in Asia, we must suppose a similar though weaker magnet, having its axis inclined to the former about 45°. In order to account for the change of declination from year to year, it seems necessary to admit that these magnets change their position slowly but regularly. As there are geological reasons for believing that the interior of the earth is in a state of igneous fusion, we do not believe that there are, in reality, any such magnets within the earth; but it seems more probable that all the phenomena of terrestrial magnetism are due to *electric currents* circulating round the globe, and that these currents are determined by the unequal temperature of different portions of the earth's surface.

Fig. 283.



505. *Disturbances of the earth's magnetism.* The intensity as

well as the direction of the earth's magnetic attraction is subject to frequent and irregular disturbances. These disturbances have been observed to take place almost simultaneously over large portions of the earth's surface.

On the 30th of January, 1836, throughout the whole of Europe, from Sicily to the Netherlands, the magnetic needle exhibited remarkable disturbances, which took place every where nearly at the same instant of absolute time.

On the 25th of September, 1841, an extraordinary oscillation of the needle was observed simultaneously at opposite points of the globe, viz., at Toronto in Canada, at Greenwich, at St. Helena, at the Cape of Good Hope, and at Trevandrum, in India.

These remarkable fluctuations have been called *magnetic hurricanes*, and generally accompany exhibitions of *the Aurora Borealis.* In the great Aurora of November 14, 1837, the range of the fluctuations of the magnetic needle at New Haven was no less than six degrees.

BOOK EIGHTH.

ELECTRICITY.

SECTION I.

ELECTRICAL ATTRACTION AND REPULSION.

506. *Origin of the name electricity.* Electricity is a term derived from the Greek word ηλεκτρον, signifying *amber*, that being the substance in which this agent was first observed.

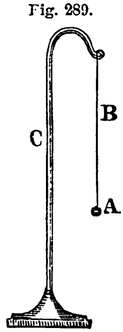
Amber, when rubbed with woolen cloth, has the power of attracting light substances, such as pith of elder, bits of paper, gold leaf, etc.

A glass tube well dried and rubbed with dry silk or woolen cloth has the same property. If the glass be presented to the knuckle of the finger, a spark will pass between the glass and finger, accompanied by a crackling sound. On bringing the glass near the face, a sensation will be produced like that which is felt when we touch a cobweb.

A stick of sealing-wax rubbed with fur produces similar effects.

507. *The electric fluid.* In order to study the laws of electricity, provide a ball, A, of the pith of elder, about a quarter of an inch in diameter, and suspend it by a fine silk thread, B, from a convenient stand, C.

Fig. 289.



If the glass tube, after being rubbed with dry silk, be brought near the pith ball, the ball will be first attracted and immediately repelled. If the tube be brought into contact successively with two pith balls thus suspended, and the balls be placed near each other, they will repel each other.

These effects are explained by supposing that there has been excited upon the glass tube a subtle fluid, which is self-repulsive; that by touching the balls, a portion of this fluid has been imparted to them, which is

diffused over their surface, and which can not escape by the silk thread; that the fluid remaining on the glass tube repels the fluid diffused on the balls, and therefore repels the balls themselves; and also the fluid diffused on the one ball repels the fluid diffused on the other ball, and the balls, being covered by the fluid, repel each other.

The fluid producing these effects is called the *electric fluid.*

When, by any process, a body is made to give signs of electricity, it is said to be *electrically excited*, or *electrified.*

508. *Vitreous and resinous electricity.* If we take two pith balls, one of which has been electrified by contact with a glass rod rubbed with silk, and the other by a rod of sealing-wax rubbed with fur or flannel, we shall find that the ball which has been repelled by the glass rod will be attracted by the sealing-wax, while the one repelled by the sealing-wax will be attracted by the glass. The electricity evolved from the glass is therefore not identical with that evolved from resins, since the one attracts what the other repels.

Hence it has been inferred that there are *two electric fluids.* These fluids are each self-repulsive, but attract each other. That which is obtained from a glass rod rubbed with silk has been called *vitreous electricity*, and that which is obtained from sealing-wax rubbed with fur is called *resinous electricity.* In unelectrified bodies, these two fluids are supposed to be combined in equal quantities, and neutralize each other. When they are separated, each exhibits its peculiar properties.

509. *Properties of the two fluids.*

Bodies electrified in the same way repel each other; bodies electrified in different ways attract each other.

If a pith ball, suspended by a silk thread, be electrified by touching it with an excited glass tube, it will be repelled by the tube, and by all other bodies which afford the vitreous electricity, while it will be attracted by excited sealing-wax and by all other bodies which afford the resinous electricity. Hence it is easy to determine which kind of electricity is furnished by a given body; for, having electrified a pith ball by excited glass, then all those bodies which, when excited, *attract* the ball afford the resinous, while all those which *repel* the ball afford the vitreous electricity.

510. *The two fluids produced simultaneously.* If, when we rub

a glass tube with a dry cloth, the hand which holds the cloth be covered with a dry silk glove, and if the cloth, after the friction with the glass, be brought into contact with two pith balls, it will repel them, and the balls will repel each other. Hence it appears that by the friction, the electric fluid is developed at the same time on the glass and on the cloth.

If, however, the ball, when it is repelled by the cloth, be brought near the glass, it will be *attracted;* or if one ball be brought into contact with the glass, and the other with the cloth, the two balls will then attract each other.

We thus see that *the two kinds of electricity are produced simultaneously; the one kind in the rubber, the other in the body rubbed.*

511. *Hypothesis of Franklin.* The preceding fact has led some to conclude that there is but *one electric fluid.* They have supposed that all bodies in their natural state have always a certain charge of the electric fluid, the repulsive effect of which is neutralized by the attraction exercised by the body upon it. The effect of friction is supposed to be to deprive the cloth of a portion of its natural charge of electricity, and to charge the glass with what the cloth loses. Accordingly, the glass is said to be *positively electrified,* and the cloth *negatively electrified.* This is the hypothesis which was adopted by Franklin. The hypothesis of two fluids is now most generally adopted; but the terms *positive and negative electricity* are often employed by those who adhere to the hypothesis of two fluids.

512. *Various bodies afford electricity.* Almost every known substance is capable of electrical excitement by friction, but the following are some of the substances which yield electricity most abundantly:

Shell lac, gutta percha, brimstone, amber;
Resins and gums of every kind;
Glass, silk, furs, hair, feathers, etc.

513. *What bodies afford vitreous electricity.* Whenever two bodies are rubbed together, and electricity is developed, one body is charged with vitreous electricity, and the other with resinous electricity; but *the kind of electricity which each substance acquires depends upon the substance against which it is rubbed.* Thus, if amber be rubbed with sulphur, it will acquire vitreous electricity; but if it be rubbed with glass, it will acquire resinous electricity.

The following table contains a number of substances arranged in such an order that, when any substance in the list is rubbed upon any other, that which holds the higher place will acquire vitreous electricity, and that which holds the lower place resinous electricity.

1. Fur of a cat.	6. Paper.
2. Polished glass.	7. Silk.
3. Woolen cloth.	8. Sealing-wax.
4. Feathers.	9. Amber.
5. Wood.	10. Sulphur.

SECTION II.

CONDUCTION—ELECTROMETERS—INDUCTION.

514. *Conductors and non-conductors.* Electricity moves over some bodies with the greatest freedom, and over others with the greatest difficulty, or scarcely at all. The former class of bodies are called *conductors*, and the latter *non-conductors.*

Of all bodies, the best conductors are the metals; while glass, resins, etc., are very bad conductors. There is no substance known which is perfectly impervious to electricity, for the intensity of the electricity may be so increased as to force it, for a certain distance, through all bodies; neither is there any body which opposes no resistance to the transmission of electricity. The following table contains a catalogue of objects in the order of their conducting power.

Conductors.	Non-conductors.
Metals: the least oxidable are the best.	Gum lac and gutta percha are the best.
Well-burned charcoal.	Amber, resins, sulphur.
Plumbago.	Wax, glass.
Pure water.	Diamond, silk, wool.
Moist snow.	Hair, feathers.
Living vegetables and animals.	Cotton, paper.
Flame, smoke, steam.	Dry air, baked wood.
Rarefied air.	India-rubber.
Moist earth and stones.	Oils, ice below $-13°$ F.

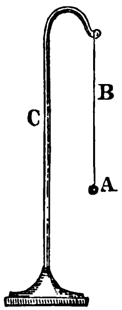
515. *Insulators.* Good non-conductors are also called *insula-*

tors, because, when a body supported by a non-conductor is charged with electricity, the charge can not escape. Thus, if a globe of metal, supported on a glass pillar, or suspended by a silken cord, be charged with electricity, it will retain the charge; whereas, if it were supported on a metallic pillar, the electricity would pass away over the surface of the pillar. An electrified body is said to be *insulated* when its connection with other bodies is formed by means of non-conductors.

Dry air is a non-conductor; but water is a conductor, and the presence of vapor in the air impairs its insulating power. Hence electrical experiments always succeed best in cold and dry weather, and bodies upon which electricity is to be developed by friction should be previously dried.

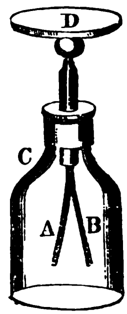
516. *Electrometers.* Instruments employed to detect the presence of electricity are called *electroscopes*, while such as are employed to measure its quantity are called *electrometers*. This distinction, however, is frequently neglected, and instruments of either kind are called electrometers. The simplest electrometer consists of a small ball of the pith of elder suspended by a silk thread. This may be called the *pith-ball electrometer*. Sometimes it is more convenient to employ two pith balls suspended side by side from the same support.

Fig. 290.



The *Gold-leaf electrometer*, represented in *Fig.* 291, consists of two narrow slips of gold leaf, AB, suspended by a metallic rod in a glass cylinder, C. The slips of gold leaf are thus insulated; they are protected from the influence of currents of air, and electricity may be communicated to them by bringing an electrified body in contact with the cover, D. In their natural state, the two slips hang in contact, but when electricity is imparted to the plate D, the leaves diverge from each other.

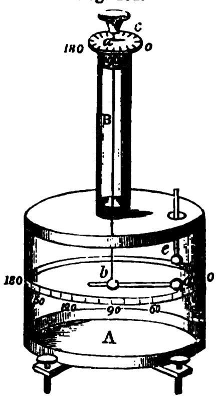
Fig. 291.



517. *Coulomb's electrometer* is an apparatus still more delicate for detecting electricity and measuring its intensity. It consists of a cylindrical glass vessel, A, having a movable glass cover, from the centre of which rises a smaller glass cylinder, B. The

latter cylinder is surmounted by a graduated circle, upon which moves an index, from which is suspended a fine platinum wire. This wire passes through the centre of the small cylinder, and supports a needle, *b*, formed of gum lac. At one extremity it carries a small disk, *d*, coated with gold leaf, and it is so balanced as to rest horizontally, while it is free to turn in either direction round the point of suspension. When it turns, it produces a degree of torsion of the supporting wire, whose reaction measures the force which turns the needle. On a level with the needle is a graduated circle for measuring the angle through which the needle is deflected. In the cover of the vessel is an aperture through which may be introduced a ball, *e*, supported by a glass rod, by which electricity is conveyed to the gilded disk of the needle, *b*.

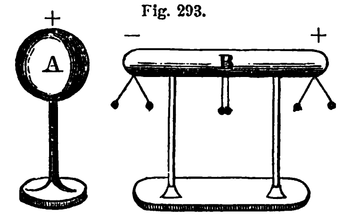
Fig. 292.



518. *Induction.* If a body, A, charged with electricity, be brought near a body, B, in its natural state, the electricity of A will act upon the two electricities combined in B, repelling the same kind of electricity and attracting the opposite electricity. If the body B be a conductor, the fluid similar to that with which A is charged, will be repelled to the side most distant from B, and the opposite fluid will be attracted to the side next to B. *This influence of an electrified body exerted at a distance upon the electricity of another body is called induction.*

Let A be a metallic ball supported on a glass pillar, and let B be a metallic cylinder similarly mounted, whose length is about ten times its diameter, and whose ends are rounded into hemispheres. Let A be charged with vitreous electricity, and let it be placed near B, but not near enough for a spark to pass. The vitreous electricity of A will attract the resinous electricity of B, and repel the vitreous electricity of B, so as to

Fig. 293.



separate them, drawing the resinous fluid toward the nearer end, and repelling the vitreous fluid toward the remote end. If a pair of pith balls be suspended from each end of the cylinder, the balls will diverge; but a pair suspended from the centre will not diverge. By means of an electrometer we may ascertain that in that end of the cylinder which is nearest to A, the electricity is resinous; and in that end which is most remote from A, the electricity is vitreous.

519. *No transfer of electricity.* In this experiment no electricity is *transferred* from A to B; for if we discharge the electricity of A, or remove A to a distance, the electricity of B immediately disappears.

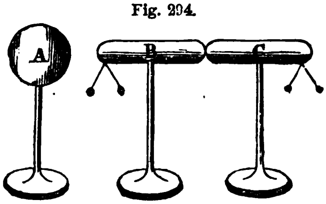
If, when the electricity of the body B has been decomposed by the action of A, we touch with the finger the remote end of B, the vitreous electricity which was driven to that part of the conductor will be conveyed away, but the resinous electricity in the other end will remain, being retained in its place by the attraction of the opposite electricity in A. The self-repellency of the fluid in A is thus neutralized by the attraction of B; and if the body A communicate with some source of feeble electricity, more of the fluid will pass into A. This will decompose more of the natural electricities of B, attracting the resinous and repelling the vitreous. If we touch with the finger the remote end of B, the vitreous electricity will be conveyed away, but the resinous electricity of the nearest end will remain, being held in its place by the attraction of the opposite electricity in A. This allows more electricity to pass into A, which again reacts on B; and thus, by the influence of induction, the electricity, proceeding from a feeble source, may acquire considerable intensity.

520. *Disguised electricity.* The electricity thus accumulated on A and B exhibits but little repulsive force, because the self-repellency of either fluid is neutralized by the attraction of the opposite fluid in the other conductor. Electricity in this condition is called *disguised electricity.* But if we remove the conductor B from the vicinity of A, the repulsive force of the fluid is immediately exhibited, and the body appears powerfully charged with electricity.

521. *Why an unelectrified body is attracted.* When the electricity of a body, A, thus acts by induction upon an unelectrified

body, B, the body B is attracted by A, because the attraction of A for the opposite electricity in the nearer end of B, is greater than its repulsion for the same kind of electricity in the remote end of B, the action in the latter case being enfeebled by distance. Hence we see why an unelectrified body is attracted by an electrified body. The two electricities residing on the unelectrified body, and which, in their natural state, neutralize each other, are first decomposed, and the opposite electricity is drawn to the end nearest to the electrified body, when attraction between the two bodies necessarily results.

Fig. 294.



If, instead of a single conductor, B, we employ two conductors, B and C, and after the electricities have been decomposed by the action of A, we withdraw C from B, we shall have an excess of vitreous electricity on C, and of resinous electricity on B. The two electricities may thus be exhibited *separate from each other.*

SECTION III.

ELECTRICAL MACHINE—LAWS OF ELECTRICAL FORCES.

522. *Parts of an electrical machine.* An electrical machine is an apparatus by means of which electricity is developed and accumulated in a convenient manner. An electrical machine consists of three principal parts:

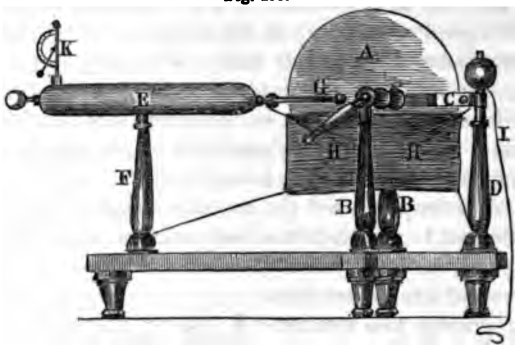
1st. The body on whose surface the electricity is evolved;

2d. The rubber, being generally a cushion stuffed with hair; and,

3d. An insulated conductor, to which the electricity is transferred, and on which it is accumulated.

The body on which the electricity is evolved is generally of glass, either in the form of a *cylinder*, or of a *circular plate*, so mounted as to be easily and rapidly moved in contact with the rubber. The plate machine is now generally preferred to any other form.

Fig. 295.



523. *Plate machine.* This consists of a circular *plate of glass*, A, two feet or more in diameter, mounted upon an axis passing through its centre, so as to be turned easily by a crank. The axis is supported by two glass columns, BB. The plate is embraced between *two cushions*, C, mounted on a glass pillar, D, and the pressure of the cushions against the plate is regulated by springs. The cushions are of leather stuffed with hair, and are coated with some *amalgam*. An amalgam may be formed by melting together one ounce of tin and two ounces of zinc, and mixing them while fluid with six ounces of mercury. When cold, it is reduced to a fine powder, and mixed with a sufficient quantity of lard to form it into a paste.

Instead of an amalgam, the deutosulphuret of tin, or *aurum musivum*, as it is often called, may be rubbed upon the cushions of the machine, and with similar results.

The *prime conductor*, E, consists of a brass cylinder, mounted on a glass pillar, F, and is designed to receive the electricity when excited. To the end of the conductor next the plate is attached an arm, G, furnished with a row of points, which are presented close to the surface of the plate, but without touching it. These points serve to collect the electricity from the surface of the plate. The lower half of the plate is covered by a *case of silk*, HH, in order to prevent the electricity of the glass from being wasted by the air, and to keep the glass free from dust. A metallic chain, I, connects the cushion with the ground.

524. If now the plate is made to revolve, vitreous electricity

is developed upon the plate, and resinous electricity on the rubber. The latter passes by the conducting chain to the ground. The former is carried on the surface of the glass until it arrives at the points projecting from the conductor. By these it is conveyed to the conductor, which thus becomes charged with vitreous electricity. If the rubber be insulated, only a small amount of electricity will be obtained.

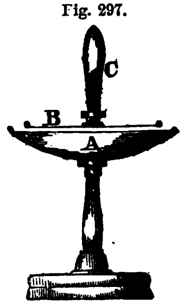
525. *Quadrant electrometer.* In order to indicate the intensity of the electricity on the prime conductor, a *quadrant electrometer* is often attached to it. This consists of a slender rod or index of very light wood, terminated by a small pith ball, and suspended from a stem of wood which is fitted to a hole in the upper surface of the conductor. For the purpose of measuring the deviation of the movable index, a graduated ivory semicircle is affixed to the stem. When the prime conductor is not electrified, the index hangs in a vertical position; but when the conductor is electrified, the index is repelled, and the height of the index affords some measure of the intensity of the electricity.

Fig. 296.

When an electrical machine is well fitted up, on turning the crank, circles of light surround the plate, and brushes of light emanate from the cushion and other parts of the machine. The prime conductor is rapidly charged with electricity, and on bringing the knuckle near it, a spark passes to a distance of several inches, and is accompanied by a loud snap.

526. The *electrophorus* is a very convenient instrument, and for many purposes may take the place of an electrical machine. It consists of a *cake of resin*, A, which is fused in a plate of metal. The surface of the resin should be as smooth as possible. On this cake we place a metal *cover*, B, consisting of a circular metallic plate, provided with an insulating handle, C, fixed to its upper surface. When the resin is beaten with fur, it takes resinous electricity. If the cover be laid upon the cake, its two electricities will be decomposed by the action of the electricity of the resin; the vitreous electricity will be attracted, and the resin-

Fig. 297.



ous electricity repelled. The former will therefore accumulate in the lower part of the cover, and the latter in its upper part. If we touch the cover with the finger, the resinous electricity will escape, and the vitreous electricity will remain, being held in its place by the attraction of the resinous electricity of the cake. This electricity, however, is not sensible, as long as the cover is in contact with the cake; but if the cover be lifted by its insulating handle, it will be found charged with vitreous electricity. This operation may be repeated an indefinite number of times, since the electricity of the cake continues unimpaired during the process. This instrument has been known to retain its power undiminished for months, and may therefore be regarded as a sort of *magazine of electricity.*

527. *Electrical repulsion.* By the aid of an electrical machine, the phenomena of attraction and repulsion may be exhibited in a most striking manner.

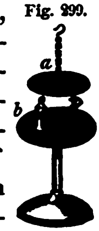
If a skein of thread or a lock of fine hair be suspended from the prime conductor, the threads will exhibit strong repulsion when electrified.

Fig. 298.

A small figure in the shape of a human head covered with hair, when placed upon the conductor and electrified, will exhibit the appearance of terror from the general bristling up and divergence of the hair.

528. *Electrical dance.* If light bodies are placed between an electrified conductor and a conductor communicating with the earth, they may be made to move with great rapidity backward and forward from one surface to the other, being alternately attracted and repelled by the electrified surface. Let a metallic plate, *a*, about six inches in diameter, be suspended horizontally from the prime conductor, and beneath it, at a distance of three or four inches, place another plate, *b*, communicating with the ground. If figures of men and women, cut out of paper or formed of pith of elder, be placed between the two plates, when the upper plate is electrified, the objects will dance rapidly up and down. They are first attracted by the upper plate,

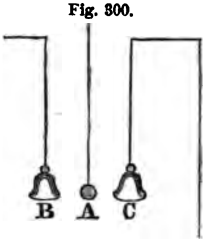
Fig. 299.



but on touching it they acquire the same kind of electricity, and are repelled. As soon as they touch the lower plate, their electricity is discharged, when they are again attracted as at first; and this motion continues until the electricity of the upper plate is exhausted.

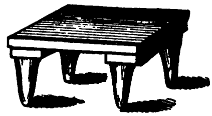
529. *Electrical bells.* If a ball, A, be suspended by a silk thread between two bells, one of which, B, is electrified, and the other, C, communicates with the ground, the ball will be first attracted to the bell B, and then repelled to the bell C. As soon as it touches the latter, it loses its electricity, when it is again attracted by B, and then repelled to C, and thus a continuous ringing of the bells is maintained.

Fig. 300.



530. *Insulating stool.* If a person stand upon an *insulating stool*, consisting of a stool with glass legs coated with varnish, the body may be electrified by communicating with the prime conductor. When thus electrified, the hair rises and stands erect, light bodies are first attracted and then repelled, and a spark may be given as from the prime conductor.

Fig. 301.



If the rubber be *insulated* while the machine is turned, the rubber and the glass plate will be found to be in opposite electrical states; a pith ball attracted by the one will be repelled by the other. If the rubber be made to communicate by a chain with the prime conductor, no electricity will be manifested, though the machine be turned ever so rapidly.

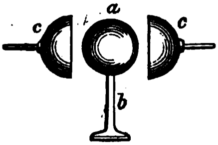
531. *Law of electrical force. The force of attraction or repulsion between two electrified bodies at different distances varies inversely as the square of the distance.* This is proved by means of the torsion balance described in Art. 517. Suppose the charge communicated to the ball e be such that the needle is repelled to a distance of 36°; then the supporting wire has been twisted 36°, and the repulsive force of the ball e upon the needle is represented by 36. If we wish to find the value of the repulsive force at a distance of 18°, we must turn the index to which the wire is fixed, in opposition to the direction of the repulsive force, until

we bring the ball within 18° of the needle. We shall find that, in order to accomplish this, the index must be turned back 126°. The torsion of the wire is now 126°+18° or 144°. The repulsive force of the ball *e* upon the needle at a distance of 18° is therefore represented by 144. The values of the repulsive forces at the angular distances of 36° and 18° are as the numbers 36 and 144. The distances are as the numbers 1 and ½, while the corresponding forces are as 1 to 4; that is, *the force of repulsion varies inversely as the square of the distance.*

By suspending a needle of lac near to an electrified sphere, and counting the number of oscillations made in a given time at different distances, it has been proved that electric attraction also follows the same law.

532. *Electricity resides wholly on the surface of bodies.* Let a spherical metallic body, *a*, be supported by a glass rod, *b*, and let two thin hollow metallic caps, *cc*, be made to fit it exactly, and let them also be furnished with insulating handles of gum lac. Let the ball *a* be electrified, and let the two caps, held by their insulating handles, be carefully applied to its surface; upon withdrawing the caps, it will be found that the whole of the electricity has been abstracted from the sphere.

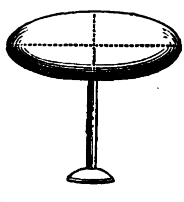
Fig. 302.



If we electrify a hollow sphere, the electricity will pass immediately to the surface, and there will be no trace of electricity on the interior.

533. *How the distribution varies.* If the electrified body be a *sphere*, we shall find that the electricity is distributed uniformly over the surface.

Fig. 303.

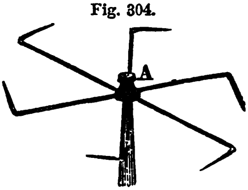


If the electrified body be an *ellipsoid*, formed by the revolution of an ellipse around its longer axis, the intensity of the electricity at the extremities of the two axes will be exactly in the ratio of the axes themselves. If, therefore, the ellipsoid be very elongated, the intensity of the fluid at the ends will be proportionally great. If the electrified body be drawn out to a *point*, the intensity of the electricity at that point will be exceedingly great, and the electricity will escape rapidly through the air.

534. *Effect of a point.* Let a metallic point be attached to the prime conductor of the electric machine, and let the machine be turned, the electricity will escape by the point nearly as fast as it is excited, and will produce a sensible current of air. If a sharp point like that of a fine needle be held in the hand and brought near the prime conductor, a similar effect will be produced.

535. *Rotation produced by the reaction of points.* The escape of electricity from points may be made to produce a variety of motions. Let several cross wires, the ends of which terminate in points bent in the same direction with respect to the axis, be supported by means of a cap upon a fine point, A, and electrified by being placed upon the prime conductor of a machine. The electricity will escape in a stream from each of the points; a current of air will thus be set in motion, which reacts upon the wire, causing it to move in the opposite direction; that is, the whole system spins rapidly round on the centre A. If we place the apparatus under the receiver of an air-pump, the motion will cease as soon as a vacuum is obtained.

Fig. 304.

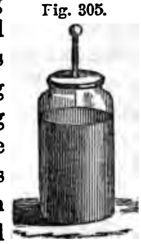


SECTION IV.

THE LEYDEN JAR.

536. *Discovery of the Leyden jar.* In 1746, a philosopher in Leyden, Holland, having filled a small glass phial partly with water, inserted a nail through the cork, and suspended it from the prime conductor of the electrical machine. After turning the machine, he attempted to detach the phial and nail, when he received a *violent shock* across his arms and breast. It was soon found that, by substituting for the water a thin metallic covering, and applying a like coating on the outside, similar effects were obtained, and thus was formed the Leyden jar. This instrument now consists of a glass jar, coated both outside and inside with tin foil, except a small

Fig. 305.



space near the top, which is either left bare or coated with varnish. A metallic rod, rising two or three inches above the jar, and terminating at the top in a brass ball or knob, is made to descend through the cover until it touches the interior coating.

537. *How the jar is charged.* If the knob of the jar be held about half an inch from the prime conductor, while the outside of the jar communicates with the earth, a series of sparks will pass between the knob and conductor, which will continue for some time, and then cease. The jar is then said to be *charged.* If now we take the *discharging rod* (consisting of a thick curved wire, with a brass ball at each end, and insulated by a glass handle), and apply one ball to the external coating of the jar, and the other to the knob of the jar, a spark of vivid light will be emitted, accompanied with a loud explosion. The jar is then said to be *discharged.*

Fig. 306.

If, after a few minutes, we apply the discharging rod a second time, a feeble spark is often perceived. This is called the *residuary charge.*

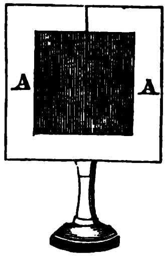
If, instead of the discharging rod, we apply one hand to the outer coating, and touch the knob of the jar with the other hand, a violent and painful sensation will be experienced, principally at the wrists, elbows, and across the breast. This sensation is called *an electric shock.*

538. *The opposite sides of a charged jar are in different electrical states, the one containing vitreous, and the other resinous electricity.* If a pith ball suspended by a silk thread be brought near the knob, it will be first attracted and then repelled; it will now be attracted by the outside coating until after contact, when it will be again repelled.

In order to charge a jar, the outside of the jar must be *uninsulated.* If we suspend the jar from the prime conductor so that the outer coating is insulated, and put the machine in operation, the jar will receive no charge. If, however, the outer coating is made to communicate with the rubber, the jar is readily charged.

539. *The Franklin plate.* The Theory of the Leyden jar is best explained by aid of the Franklin plate. This consists of a plate of glass about a foot square, the middle of the glass on either side being covered with tin foil, leaving a free margin of

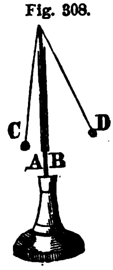
Fig. 307.



about three inches. The uncovered parts of the glass should be varnished in order to improve their insulation. If now we bring one side of the plate into communication with the prime conductor, a portion of vitreous electricity will pass to the coated surface. The electricity of the front surface decomposes the combined electricities of the back surface, and, as soon as we place the latter in communication with the ground, the vitreous electricity will pass into the ground, while the resinous electricity is retained by the attraction of the vitreous electricity of the front surface. The self-repulsive force of the electricity on the front surface, being balanced by the attraction of the opposite electricity on the back surface, allows more electricity to pass from the prime conductor to the front surface, which again, by induction, increases the resinous electricity on the back side. This resinous electricity, by its attraction, balances the self-repulsive force of the vitreous electricity on the front side, allowing a still further accumulation until the plate is fully charged.

540. *Free electricity of the plate.* The attraction of these two opposite electricities for each other nearly balances their self-repulsive force, and diminishes their action on surrounding bodies. Electricity in this condition has been called *disguised electricity.* If the amount of electricity on the two coatings is the same, the self-repulsive force of either electricity will not be quite balanced by the attraction of the electricity on the opposite coating, because this attraction is somewhat enfeebled by distance. There will, then, be a small amount of *free electricity* on each side of the plate. If a pith ball be attached by a silk thread to each of the coatings of the pane of glass, and the pane be charged as already described, when the amount of electricity on each coating is the same, each pith ball will stand out a little from the plate, indicating a feeble repulsion. If now we touch the side A with the finger, the pith ball C on that side will immediately fall, while that on the opposite side will rise to double its former height. By this contact we only draw off the *free* electricity on that side

Fig. 308.



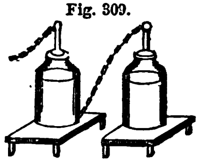
of the plate; the principal charge is retained in its place by the attraction of the electricity on the opposite side. If now we touch the side B with the finger, the pith ball D on that side will immediately fall, while the other will rise to the former height of D. If we touch the side A, the ball C will fall and D will rise, and this alternate touching of the coatings may be repeated some hundreds of times before the plate is entirely discharged.

If, instead of this gradual discharge, a communication is made between the two coatings by a metallic wire, the whole of the electricity which was accumulated upon one coating, instantly combines with the electricity on the other coating.

541. *Theory of the Leyden jar.* The Leyden jar differs only in form from the Franklin plate, but is far more convenient for use. In order to receive a charge, the outside of the jar must be uninsulated, in order to allow the escape of the electricity of the outer coating, which is repelled by the electricity of the inner coating of the jar; or the outer coating may be made to communicate with the rubber, in which case the repelled electricity combines with the opposite electricity of the rubber.

542. *How a second jar may be charged.* If, instead of touching the outer coating of a jar supported on an insulating stand, we bring near it the knob of a second jar whose outer coating communicates with the ground, the electricity which is expelled from the outer coating of the first jar passes to the inner coating of the second jar, and thus both jars are charged. In like manner, a third jar may be charged by the electricity expelled from the outer coating of the second jar, and so on indefinitely.

Fig. 309.

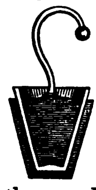


543. *A jar may be charged with resinous electricity by presenting its knob to the rubber*, the rubber being insulated, and the prime conductor uninsulated. For this purpose, the chain usually attached to the rubber may be transferred to the prime conductor. A jar may also be charged with resinous electricity by holding the jar by its knob, and bringing its outer coating near to the prime conductor.

544. *The electricity with which a jar is charged resides on the lass,* and the coating of tin foil only serves to put all the par-

ticles on the inside of the jar in communication with each other, and also those on the outside, so that all the electricity may be discharged at the same instant. This is shown by a jar with movable coatings. *Fig.* 310 represents a conical glass jar, having a loose coating of metal fitted to its interior, with a rod and ball projecting from it, and a similar loose coating fitted to its exterior. Let this jar be charged with electricity in the usual manner. Let the internal coating be then removed, and let the jar be raised out of the external coating. The two coatings may be handled and brought into contact with each other, and no spark passes; but if a pith ball be brought near either surface of the glass jar, it will indicate the presence of electricity. If the two metallic coatings be restored to their former position, and the discharging rod be applied, a spark will pass, and the jar will be discharged.

Fig. 310.



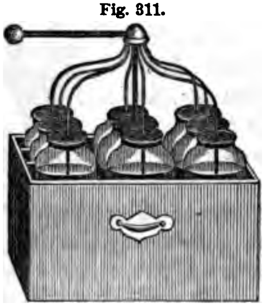
545. *When two jars are charged, the one with vitreous, the other with resinous electricity, on connecting the insides of both jars by means of the discharging rod, there will be no discharge unless the outsides be also connected.* The reason is that, although each electricity attracts the opposite electricity of the other jar, the electricity on the inside of each jar is retained in its place by the attraction of the opposite electricity on the outside of the jar, and the two electricities on the inside of the jars can not combine, unless the electricities on the outside are also permitted to combine.

546. *Free electricity of the jar.* As has been already shown in the case of the Franklin plate, Art. 540, the Leyden jar, when charged, always exhibits some *free* electricity. If the amount of electricity on the two coatings be exactly equal, then, since the attraction of the two electricities for each other is somewhat enfeebled by distance (the thickness of the glass), this attraction will be somewhat less than the self-repulsive force of either fluid. If we touch the outer coating of the jar, we draw off all the free electricity from that side, and the amount of free electricity on the inside will be increased; and if a pith ball be brought near to the knob of the jar, it will be first attracted and then repelled. This free electricity may be employed to produce all the phenomena of attraction and repulsion described in Arts. 527–9. If two

jars be charged in opposite ways, and set near each other on a table, a pith ball suspended by a silk thread between the knobs of the two jars, will vibrate back and forth until both jars are discharged.

547. *Electrical battery.* By combining together a large number of jars, we are able to accumulate an enormous quantity of electricity. For this purpose, all the interior coatings must be made to communicate by metallic rods, and a similar union must be established between the exterior coatings. When thus arranged, the whole series may be charged as if they formed but one jar, and the whole of the accumulated electricity may be discharged at once. Such a combination of jars is called an *electrical battery.* The battery is used whenever we require a greater charge than can be obtained from a single jar.

Fig. 311.



SECTION V.

EFFECTS OF ELECTRICITY.

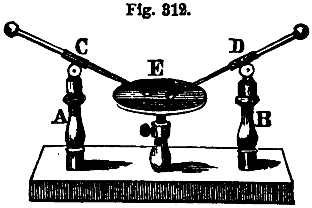
548. *Mechanical effects.*

Imperfect conductors through which a powerful electric charge is passed are rent asunder with violence. When the charge is passed through a thick card, a hole is made, which presents the rough appearance of a *burr* on each side. A rod of wood half an inch thick may be split by a strong charge transmitted in the direction of its fibres. A strong charge passed through water scatters the liquid in all directions. If we fill a small tube with oil, and insert two wires through corks in the opposite ends of the tube, by a moderate charge the tube will be burst into fragments. Upon a piece of dry wood, paste a narrow strip of tin foil, and near the middle make an interruption in the foil about one eighth of an inch in breadth. Over this point of interruption place a few wafers, and then pass the charge of a Leyden jar along the tin foil; the wafers will be scattered with great vio-

lence. If the charge of a battery is passed between several plates of glass, the glass is usually splintered.

549. *Universal discharger.* Experiments of this kind are most conveniently performed with the assistance of the *universal discharger.* This consists of a wooden table, to which two glass pillars, A and B, are attached. At the summit of these pillars are fixed two brass joints, C and D; to these joints are attached brass rods, terminated by balls, and having glass handles. Beneath the balls is a small wooden table, E, sustained on a pillar capable of having its height adjusted by a screw. The substance to be operated on is placed upon the small table between the balls; the outer coating of a Leyden jar is made to communicate with one of the rods by means of a chain, and the knob of the jar is applied to the other rod.

Fig. 312.



550. *Thermal effects. A current of electricity passing through a conductor generally raises its temperature.* If the conductor be sufficiently large, no elevation of temperature will be perceived; but a small wire may be heated, or even melted, by an electric discharge. A fine steel wire $\frac{1}{250}$ inch in diameter is easily melted by electricity. A single jar, exposing a coated surface of about 190 square inches, will be sufficient to melt such a wire two inches long. With a battery exposing forty feet of coated surface, eighteen feet of such wire may be melted by a single discharge. A strip of gold or silver leaf will be burned by the discharge of a jar having two square feet of coating.

551. *Ether and alcohol ignited.* Ether or alcohol may be fired by passing through it an electric charge. Set a small and shallow metallic dish upon the prime conductor, and pour into it a little ether. When the machine is in action, bring the finger near the surface of the ether, and the ether is instantly fired. The ether is fired with equal facility when the spark is passed through a lump of ice. Alcohol may be fired in a similar manner, but requires a stronger charge of electricity. If it be previously warmed, it may be fired with greater facility.

552. *Resin burned.* Pulverized resin, such as that of colophony,

is easily ignited. Take a bent wire eight or ten inches in length, wind a small lock of cotton about one end so as to form a compact ball, and roll this ball in pulverized resin. Bring this ball near the knob of a charged Leyden jar, while the other end of the wire touches the outer coating of the jar, and the resin, together with the cotton, is easily ignited. Phosphorus is readily ignited by passing through it the charge of a small Leyden jar.

553. *Gunpowder exploded.* Gunpowder may be ignited by electricity. Upon a piece of dry wood paste a narrow strip of tin foil, and cut away the foil in two or three places, so as to make interruptions about one eighth of an inch in breadth. Over one of these interruptions pour a small quantity of gunpowder. Take a lock of candle-wick about a foot in length, moisten it with water, and attach one end of it to the discharging rod, while the other end lies upon the strip of tin foil. By passing the charge of an ordinary jar along the moist thread and through the tin foil, the powder will be ignited. The use of the moist thread is supposed to be to retard the flow of the electricity. Without some such contrivance, the powder is commonly scattered without being ignited.

554. *Electric pistol.* Hydrogen gas mixed with a small quantity of atmospheric air is easily exploded by a spark of electricity. Take a stout glass tube, closed at one end, and having two wires passed through its side, so as to admit of a spark being taken within the tube. Fill the tube with a mixture of hydrogen and oxygen, or of hydrogen and atmospheric air. Close the tube with a cork, and pass a spark through it; a loud explosion will follow, and the cork will be expelled with violence. This apparatus is often constructed in the form of a pistol, and is called the *electric pistol.*

If we allow the gas to flow from a burner of a common gas-pipe, the gas is readily ignited by passing a small electric spark through it.

555. *Luminous effects.* The electric fluid is not luminous. An insulated conductor, however strongly charged, is never luminous so long as the fluid continues in repose. Neither is light roduced when the electricity flows through a good conductor fficiently large. But if the fluid, having considerable intensity, lischarged through a resisting medium, light is produced.

556. *The electric spark.* The electric spark does not consist of a luminous point which moves from one body to another. The light, on the contrary, manifests no progressive motion. The spark consists of a thread of light which for an instant seems to connect the two bodies, and is not extended in a straight line, but has a zigzag form.

The spark received from the prime conductor upon a large metallic ball is short and brilliant, while that received on a small ball is longer and less intense. The *zigzag form* of the spark has been ascribed to the effect of minute conducting particles that are floating in the air a little removed from the direct line of passage, causing the fluid to dart off first to one side and then the other; but it is more probably due to the condensation of the air before the fluid, causing it to turn off in a direction in which the resistance is less, but soon, experiencing renewed resistance, it again turns off in a new direction.

The *length* of the spark varies with the power of the machine. In Harlem, Holland, is a machine consisting of two plates of glass, each five feet and five inches in diameter, which gives a spark two feet in length.

557. *Sparkling tubes.* If the electric fluid be transmitted through a metallic conductor which is not continuous, a spark will occur at every separation. Various devices are formed by peculiar arrangements of these interruptions in the conductor. Paste a narrow band of tin foil on a glass tube, so as to run round it in a spiral direction, and with a pen knife cut across the tin foil at frequent intervals. If then one end of the tube be held in the hand, and the other be presented to an electrified conductor, a brilliant line of light will surround the tube, which has been called the *spiral tube*. By a proper disposition of an interrupted line of metal on a flat piece of glass, a word is made to appear in letters of light in a dark room.

Fig. 313.

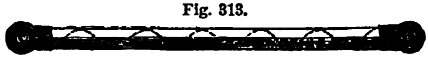
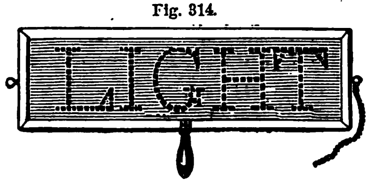


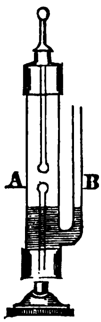
Fig. 314.



558. *The light of the electric spark is caused by the mechanical*

compression of the air that takes place when the explosion occurs, in the same way that light is produced when air is compressed in a syringe. The effect of the passage of the electric fluid through air is shown by Kinnersley's air thermometer. It consists of a glass tube, A, closed at both ends by air-tight brass caps, through each of which passes a movable wire terminated within by a small ball. To an aperture in the bottom of the lower cap, is fitted a bent tube, B, of glass, which turns upward, and is open at both ends. Into this tube is introduced a quantity of colored liquid sufficient to cover the bottom of the cylinder, A, and rise a little way into the tube B. A spark from a Leyden jar being passed between the two balls, the liquid suddenly rises in the tube B, but falls again immediately after the explosion.

Fig. 315.

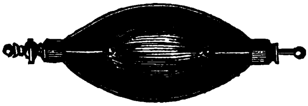


This experiment shows that by the passage of the electric spark, the contiguous particles of air are rendered powerfully self-repellent, and this must cause a sudden *compression* of the particles next adjacent.

The light and heat resulting from an electric discharge are due to *the same cause;* for heat, when it attains a certain intensity, always develops light. When a steel wire is melted by an electric discharge, it is of course rendered luminous. The cause of this heat is not well understood, but it seems to result in some way from the *resistance* opposed by the medium through which the electricity passes. A feeble spark may be obtained under water by a discharge through two wires not quite in contact with each other.

559. *The electric fluid passes with increased facility, and to a greater distance, through rarefied air.* When the spark from the prime conductor will pass only five or six inches in the open air, it will readily pass *six feet* or more through an exhausted tube. In rarefied air the light is more diffused and less intense, and acquires *a reddish or violet color.* *Fig.* 316 represents an elliptically-shaped glass vessel for exhibiting this experiment. This vessel may be screwed to an air-pump, and when the air is exhausted, the electricity will readily pass from

Fig. 316.



one ball to the other, and fill the whole vessel with *a violet red light.* This light bears so close a resemblance to that of the *Aurora Borealis* as to suggest the probable origin of that meteor. If a little air be admitted into the vessel, the light will be less diffuse; and the more air we admit, the more nearly will the light approach to the form of the ordinary electric spark.

This experiment is easily performed with a glass tube six feet in length. When the air has been well exhausted, the electricity fills the entire tube with a diffuse rosy light. Electricity would probably develop *no light* in passing through *a perfect vacuum;* but a feeble light is perceived when electricity is transmitted through the best vacuum which we have been able to produce.

560. *The color of the electric spark may be varied by passing it through different media.* If the charge of a Leyden jar be passed through a ball of ivory, it will exhibit a *crimson* light. A lemon, an orange, or an egg, treated in the same manner, is rendered beautifully luminous. A lump of sugar gives a *brilliant green light,* which remains for some time after the spark has passed. If a strong charge be passed through a piece of dry chalk, the track of the discharge will be marked by a streak of light *which will continue for several seconds.* Fluor-spar exhibits an *emerald green light,* which continues to glow in the dark for some seconds.

561. *Light from a pointed conductor.* When the electric fluid escapes from a pointed conductor in the dark, it presents the appearance of a *brush* of light, which continues to be visible as long as the machine is in action. A brush of light escapes from each point of the revolving fly described in Art. 535. The effect of a point is sensible to a great distance. When a current of sparks is passing between the prime conductor and a large ball at the distance of a few inches, if a fine needle held in the hand be presented to the prime conductor at a much greater distance, the sparks will immediately cease. The electricity passes to the point in preference to the ball, and in a dark room the point appears tipped with light. The efficacy of a lightning-rod depends principally upon this property of points. *A pointed conductor draws off an electric charge silently and from a great distance, while electricity passes to a ball through a less distance, and with an explosion.*

Fig. 317.

562. *Magnetic effects.* When a stream of electricity passes over a steel bar not previously magnetic, the bar is instantly rendered magnetic. The following is one mode of performing this experiment. Take a fine copper wire wound with silk like common bonnet wire, and coil it spirally round a small glass tube, forming a large number of coils nearly or quite in contact with each other, and let the two ends of the wire project a few inches. Introduce into this tube a steel needle not magnetic. By passing the charge of a small jar through this wire, the needle will be instantly rendered magnetic. If we reverse the position of the needle in the tube, end for end, and pass a second charge through the wire, the poles of the needle will be reversed. This subject will be treated more fully in Book ninth, Section iv.

563. *Physiological effects. Whenever the animal system is made a part of the conducting communication between the inside and outside of a charged Leyden jar, a shock is received.* Place a charged jar on a metallic plate, and, grasping a metallic rod in each hand, touch one of them to the plate and the other to the knob of the jar, and a sudden convulsion will be experienced. A slight charge affects only the *fingers* or the *wrists;* a stronger charge convulses the *arms*, and a still greater charge convulses the *breast.* The discharge of a single jar is sufficient to kill birds and other small animals; the discharge of a moderate-sized battery will kill rabbits; and a battery of twelve square feet of coated surface will kill a large animal, especially if the shock be transmitted through the head.

564. *How the shock may be communicated.* The shock may be communicated to any number of persons at once. Let several persons join hands, while the first holds a metallic rod with which he touches the outside of a charged jar, and the last holds another rod with which he touches the knob of the jar. The whole number will receive the shock at the same instant. The strength of the shock is, however, somewhat diminished by passing through a long circuit.

The shock may be limited to any part of the body, by placing two metallic plates connected with the two coatings of the jar on opposite sides of the part through which it is desired to transmit the shock.

By means of the insulating stool, the most delicate shocks

may be given by drawing off the charge through imperfect conductors. By means of a pointed piece of wood, electricity may be drawn from the eye so gently as to produce no injury.

SECTION VI.

THEORIES OF ELECTRICITY.

565. *Is electricity material?* There are many electrical phenomena which naturally suggest the idea of the rushing of a stream of particles having *great momentum*, such as the force with which electricity bursts asunder the firmest substances; the sound which attends its passage through the air; the line of light which marks its course; the stream of air which proceeds from a pointed conductor when electricity flows from it, etc. These phenomena, however, only indicate the sudden action of a *repulsive power* exerted among the particles of matter which are situated near the line of electric discharge. A charge of electricity adds nothing to the weight of a body; and since electricity is imponderable, it is probably also immaterial.

566. *Is there an electric fluid?* Electricity exhibits some of the properties of a fluid. Its attraction and repulsion; its unequal distribution over the surface of a conductor; its being confined to the surface of bodies by the pressure of the atmosphere; and its accumulation in the Leyden jar, naturally suggest the idea of an elastic fluid of extreme tenuity.

567. *Are there two electric fluids or only one?* The theory of Franklin supposes that there is but one electric fluid; that every body in its natural state has a certain charge of this fluid, whose repulsion is neutralized by the attraction exercised by the body upon it. When a body has more than its natural share of electricity, it is said to be *positively* electrified; when it has less than its natural share, it is said to be *negatively* electrified. In order to explain how bodies negatively electrified repel each other, it is necessary to admit that unelectrified matter is self-repellent. This theory then assumes,

1st. Electricity repels electricity;

2d. Electricity attracts matter;

3d. Matter, when unelectrified, repels matter.

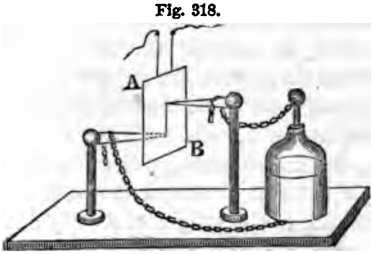
By the aid of these three hypotheses nearly all the known phenomena of electricity may be explained.

The theory of Du Fay supposes that there are two electric fluids, which, for the sake of distinction, are called the *vitreous* and *resinous* fluids. Each of these fluids repels itself, but attracts the opposite fluid. When they pervade a body in equal quantities, they neutralize each other, and the body is said to be unelectrified.

568. *Arguments for these theories.* The following facts have been urged in favor of one or the other of these theories.

The appearance of a current from the positive to the negative side of a Leyden jar. If a card, AB, colored with vermilion, be placed between the points of the universal discharger, about an inch distant from each other, and the charge of a Leyden jar be passed through it, the card is perforated where the point communicating with the negative side of the jar had touched it. At the edge of the perforation, there is a small *burr* on each side of the card. If the experiment be tried under the receiver of the air-pump, we usually find several perforations about midway between the two points. Hence this experiment does not prove that the electric fluid moves only in one direction, but simply that *air offers greater resistance to resinous than to vitreous electricity.*

Fig. 318.



569. *Burr on each side of a card.* When a card is perforated by an electric discharge, the hole exhibits a burr on *each side* of the card. This fact has been supposed to indicate *two currents* in opposite directions. But this protrusion is not due to the *momentum* of the electricity, but simply to its *repulsive power.* The particles of the card, being strongly electrified, become self-repellent, and separate in *the direction of the least resistance,* that is, laterally.

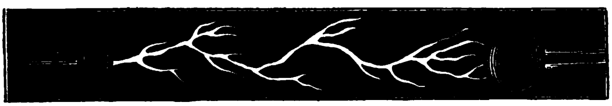
570. *Current from an electrified point.* If two sticks of sealing-wax be laid parallel to each other on the table of the universal discharger, and a pith ball be placed in the groove between them, midway between the two points of the discharger, on passing a

small charge from one wire to the other, the ball is driven from the positive to the negative wire. The flame of a candle, placed between the points of the universal discharger, is constantly blown from the positive to the negative side. These and many similar experiments have been regarded as proving that there is but one electric fluid, and that *it always moves from the positive to the negative side of the jar;* but all these facts are consistent with the theory of Du Fay, when we admit that air offers greater resistance to resinous than to vitreous electricity.

A current issues from a point negatively electrified, as well as from one positively electrified. If a pointed conductor be connected with the insulated rubbers of an electric machine, a pith ball will be repelled by the current of electricity which issues from the point.

571. *The form of the electric spark* has been thought to indicate the motion of a single fluid proceeding from the positive to the negative conductor. The spark from a powerful electric machine exhibits *lateral* branches, all of which diverge from the side of the positive conductor, as shown in *Fig.* 319. But this is per-

Fig. 319.



haps nothing more than a necessary consequence of the principle already stated, that vitreous electricity experiences less resistance from the air than resinous electricity.

572. *Neutral point in the spark.* When a spark is received from an ordinary machine, the extreme portions of the spark are usually much brighter than the middle. This imperfectly illumined part has been supposed to be the spot where the two electricities unite and *neutralize each other*. This appearance may, however, be explained by supposing that the electric fluid, on account of its self-repellency, passes from one ball to another in streams diverging from each ball, and presenting, therefore, the largest section near the middle. The result of such a diffusion would be a light of greatly diminished intensity midway between the balls.

573. *Conclusion in favor of two fluids.* The fact that resinous electricity (no less than vitreous) resides wholly on the surface

of a conductor, and spreads itself over the conductor according to the same laws as vitreous electricity, appears to indicate that resinous electricity is as truly a fluid as vitreous electricity. If, then, we admit that there is one electric fluid, *we seem bound to admit the existence of two fluids.*

574. *Velocity of electricity.* The velocity of electricity, when in motion, presents a serious difficulty to our admitting the existence of any electric fluid. This velocity is prodigiously great; so great that it can only be measured by the most delicate methods; but there is good reason to believe that when electricity has considerable intensity, and traverses a good conductor, its velocity is scarcely, if at all, less than that of light, or 200,000 miles per second.

575. *Duration of the spark.* The spark drawn from an electric machine appears to continue visible about the tenth of a second; but this apparent duration results from the impression made on the retina of the eye. The actual duration of the spark can scarcely exceed *the millionth part of a second.* This is proved by the following experiment. Let a white disk be mounted upon an axis, so that it may be revolved with extreme rapidity, and let a black cross be painted on the disk. Let now the disk be revolved in a dark room, and let it be illumined by a spark from the electric machine; the cross will be distinctly seen, and will *appear absolutely stationary;* in other words, however rapid be the rotation of the disk, the cross does not revolve through any visible angle during the continuance of the spark.

SECTION VII.

ATMOSPHERIC ELECTRICITY.

576. *Lightning and electricity are identical.* This identity was fully established by Dr. Franklin, June 15th, 1752. He formed a kite by attaching a silk handkerchief to two light strips of cedar in the form of a cross, and on the approach of a storm raised his kite with a pointed wire attached to it. He fastened a key to the end of the hempen cord, and secured the cord to a post by means of a silk lace. The string of the kite having become wet by the falling rain, he presented his knuckle to the key,

and obtained a *stream of brilliant sparks*. With these sparks alcohol was fired, jars were charged, and other experiments performed.

577. *The atmosphere generally contains free electricity.* This fact is ascertained by means of an insulated metallic rod, elevated to some height above the ground, and communicating at its lower end with an electrometer. In order to collect the electricity of the higher regions of the air, a kite may be raised, in the string of which a slender metallic wire should be interwoven, to afford a conductor for the electricity.

In the ordinary state of the atmosphere, its electricity is invariably *positive*, and is stronger in winter than in summer, and stronger during the day than the night. On the first appearance of fog, rain, or snow, the electricity of the air is generally *negative*, and often highly so; but it afterward undergoes frequent transitions to opposite states. On the approach of a thunderstorm, these alternations succeed one another with remarkable rapidity.

578. *The clouds*, consisting of immense masses of aqueous vapor, are tolerably good conductors, and *contain a considerable quantity of free electricity*. Two clouds, which are in different electrical states, act upon each other through the intervening air, and, when sufficiently near to each other, a discharge takes place in the form of a flash of lightning, accompanied by the sound of thunder. When an electrified cloud and the neighboring earth are in opposite electrical states, a discharge may take place to the earth. This discharge often takes place through the medium of the nearest most prominent conductor, as a tree, a building, or an animal. In such cases the tree is often riven in sunder, the building is damaged and sometimes set on fire, while animals are severely injured and sometimes killed.

579. *Returning stroke.* It frequently happens that serious effects are produced at a considerable distance from the spot where a discharge of lightning has taken place, and even when there has been *no visible passage of electricity from a cloud to the earth.* This might happen in the following manner. A large cloud, positively electrified, by its inductive action decomposes the electricities present in the neighboring earth, attracting the negative electricity to the surface, and repelling the positive electricity to

a distance. If the electricity of this cloud should be discharged into another cloud, or into some elevated object on the earth's surface near the extremity of the cloud, the electricity repelled from the surface of the earth would instantly return, and an animal in the neighborhood would receive a *shock,* which might even destroy life. Such an effect of electricity is called the *returning stroke.*

580. *Rules for lightning-rods.* Buildings may be protected against the effects of lightning by means of *lightning-rods.* These consist of metallic conductors, usually fixed against the sides of a building, their upper extremities extending some feet above it, while the lower end is buried in the earth. In order that a lightning-rod may afford complete protection, the following rules should be observed.

1st. *The rod should be of sufficient size.* If the rod is of iron, it should be from half an inch to an inch in diameter. If of copper, one third of an inch may suffice.

2d. *The rod should be continuous from top to bottom.* The parts may be made separate, but when the rod is in its place, they should be secured together so as to form a continuous surface, since links and interrupted joints oppose resistance to the passage of the electricity.

3d. *The rod should terminate at the top in a sharp point.* In order that the point may not be blunted by rust, it should be covered with gold leaf, or should be made of solid silver or platina.

4th. *The rod should terminate at the bottom in wet earth.* Dry earth is a poor conductor of electricity. If, then, the rod should terminate in dry earth, the electricity, during a thunder-storm, must accumulate upon the conductor; it will pass off laterally to other conductors, and occasion the same damage as if there were no lightning-rod. The rod should enter the earth at least five feet, and in dry sand not less than ten feet; and in such situations it is better to connect the end of the rod with a well or spring of water.

5th. *The rod should rise considerably above the highest part of the building.* It has generally been assumed that a rod *will protect a circle whose radius is twice the height of the rod;* but this rule is not always quite safe; and, unless a building be very small, it should have more than one rod. *Chimneys* need especial protec-

tion, both on account of their elevation, and because the soot is a good conductor, as is also the vapor issuing from a chimney in which a fire is burning.

581. *What is the source of the electricity of the atmosphere?*

1st. Electricity is produced by the *evaporation of salt water*. On the cap of a gold-leaf electrometer place a small vessel containing a little salt water, and drop a red-hot ball into the water. The leaves of the electrometer will instantly diverge. If the experiment be tried with distilled water, very little, if any, electricity will be obtained; but electricity is developed if the water contains even a small amount of saline matter. Evaporation is probably the principal source of atmospheric electricity, for all the water upon the face of the earth is impregnated more or less with different salts.

2d. Electricity is produced by the *friction of moist air against other bodies*. When high-pressure steam issues from a boiler through a proper escape-pipe, electricity is abundantly produced, the steam being charged with vitreous and the boiler with resinous electricity. Faraday maintains that the electricity in this case is due to the friction of the liquid particles mixed with the steam against the inside of the pipe. Perhaps a similar principle operates in nature when a mass of air, charged with a large amount of condensed vapor, is impelled violently onward during a thunder-storm.

O

BOOK NINTH.

VOLTAIC ELECTRICITY.

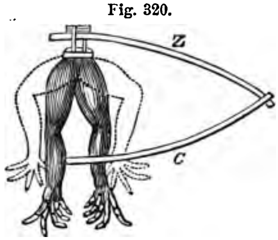
SECTION I.

VOLTAIC BATTERIES.

582. *Experiment with plates of silver and zinc.* In the year 1767, Sulzer, of Berlin, remarked that if a plate of silver be placed on the tongue, and a plate of zinc beneath the tongue, a peculiar *metallic taste* will be perceived when the ends of the plates are brought in contact. If the silver plate be pressed between the upper lip and gums, a *flash of light* will be perceived when the two plates are brought in contact. The same effect is produced whether the experiment be tried in daylight or dark, whether the eyes be open or shut.

583. *Discovery of Galvanism.* In the year 1790, Galvani, professor at Bologna, observed the contractions in the muscles of a dead frog when a spark was drawn from the conductor of an electrical machine. He afterward discovered that similar convulsions may be produced without an electrical machine in the following manner.

Fig. 320.



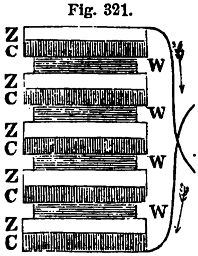
Take a narrow strip of copper, C, and another of zinc, Z, and let them be riveted together at one end. Apply one of the metals to the crural nerves of a frog recently killed; then, if the other metal touch the toes of the frog, the legs will be violently *convulsed.*

Galvani supposed that the muscular system of animals contains positive electricity, and the nervous system negative electricity, and that, when the two are connected by a metallic wire, a discharge takes place like that of the Leyden jar.

584. *Voltaic pile.* Professor Volta, of Pavia, contended that

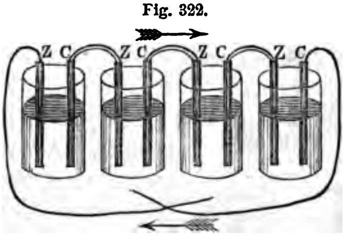
the electricity in the preceding experiment was developed by the *contact* of the two metals, copper and zinc; and in 1800 he announced an arrangement called the *Voltaic pile,* by which the electrical effect was very much increased. The Voltaic pile is constructed in the following manner. Take a large number of circular pieces of copper and zinc, all of the same size, and also circular disks of thick woolen cloth soaked in salt water. Form a pile of these disks by laying down first a disk of copper, next zinc, and upon it wet cloth; then again copper, zinc, and wet cloth, and so on until we obtain a pile a foot or more in height, taking care always to preserve the same order throughout the series. If we touch the lowest disk of the pile with a moistened finger, and the highest disk with a finger of the other hand, a distinct shock is felt similar to that from a Leyden jar. The shock is experienced whenever the circuit is completed by touching the two ends of the pile with the moistened fingers. The electricity thus developed has been termed *Galvanism,* or *Voltaic electricity.*

Fig. 321.



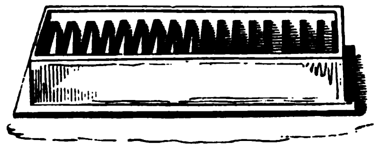
585. *Volta's cup battery.* Volta soon afterward proposed a different arrangement, in which the metallic plates, instead of being piled one above the other, are placed side by side in a vertical position, and combined together in pairs, consisting each of one zinc and one copper plate, connected at their upper edges by slips of metal. A number of glasses must be provided, and filled with some acid or saline solution, and in each is placed a plate of zinc and a plate of copper, in such manner that the copper plate of the first cup is connected with the zinc plate of the second cup, and so on, taking care to preserve the same order throughout the series. If the plates at the ends of the series be connected by wires, the current of positive electricity will flow in the direction represented by the arrows.

Fig. 322.



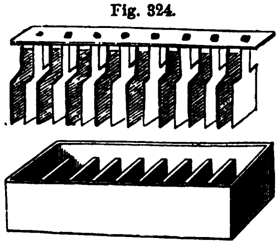
586. *The trough battery.* Volta's cup battery was superseded in 1801 by the *trough battery.* This consists of a box several feet long, and 3 or 4 inches square at the ends. Each pair of zinc and copper plates was soldered together, and the compound plates were fixed in grooves in the sides of the trough at intervals of about half an inch, forming thus a series of narrow cells. Into these cells is poured diluted acid, and the circuit is completed by bringing the two wires proceeding from the ends of the battery, in contact with one another.

Fig. 323.



In 1808, the battery was still further improved by Dr. Wilkinson, who attached the zinc and copper plates to a bar of wood, and immersed them, when required for use, in a trough of earthen-ware furnished with partitions of the same substance, and filled with dilute acid.

Fig. 324.

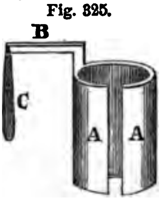


Since 1808, the Voltaic battery has undergone a great variety of improvements, but the forms now most generally employed are those of Grove and Bunsen.

In all Voltaic batteries, zinc (which is readily acted upon by an acid) constitutes one element; and some substance which is but little affected by acids, such as copper, platina, etc., constitutes a second element. Some weak acid is used to act upon the zinc, and in some instances the two elements are immersed in different acids.

587. *Grove's battery.* Grove's battery is the one most generally used in this country, and is constructed in the following manner. AA represents a hollow cylinder of zinc, about three inches high and two in diameter, coated with an amalgam of mercury, and having an opening on one side to allow a free circulation of the liquid. It has a projecting arm, B, to which is attached a strip of platinum, C, about one inch wide and three inches long,

Fig. 325.



and having the thickness of tin-foil. The zinc cylinder is placed in a glass tumbler containing sulphuric acid, diluted with about twelve times its bulk of water. Within this cylinder is placed a porous cup, D, made of earthen-ware, baked without being glazed, and filled with strong nitric acid. This cup allows liquids to pass slowly through it, and, when wet, offers but little resistance to the electric current. Within this cup is suspended the strip of platinum fastened to the end of the zinc arm projecting from the adjoining zinc cylinder. *Fig.* 327 represents a battery consisting of twelve such combinations.

Fig. 326.

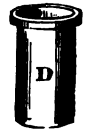
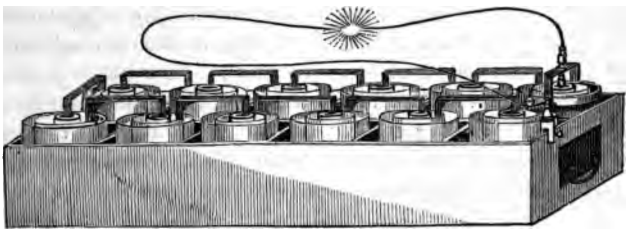


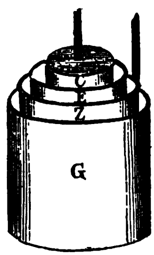
Fig. 327.



With a single cup, a feeble spark is perceived when a wire connected with the platinum is brought in contact with a wire proceeding from the zinc. The power increases with the number of cups. With a Grove's battery of 24 cups (each zinc cylinder being connected with the platinum of the succeeding cup), nearly all the experiments required to illustrate the principles of Voltaic electricity may be performed.

588. *Bunsen's battery* is similar to Grove's, substituting a cylinder of charcoal for a strip of platinum. The charcoal cylinder used for this purpose is made from the residue taken from the retorts of gas-works. The apparatus, with all its parts combined, is represented in *Fig.* 328, where the zinc cylinder Z is placed in the glass vessel G, the porous cup E within the zinc, and the charcoal cylinder C immersed in the nitric acid contained in E.

Fig. 328.

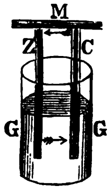


Smee's battery is frequently used, especially for purposes of gilding. It consists of a plate of iron or silver

covered with platinum, and suspended between two plates of zinc which have been amalgamated with mercury. The plates are immersed in a porcelain vessel containing dilute acid.

589. *Theory of the Voltaic battery.* In order to explain the theory of the battery, take a plate of zinc, Z, two inches wide and four inches long, and let it be amalgamated by immersing it in dilute sulphuric acid, and rubbing over it a few globules of mercury. Place the amalgamated zinc in a glass cup, GG, containing twelve parts of water and one part of sulphuric acid. Almost immediately the surface of the zinc becomes covered with myriads of minute bubbles of gas. These consist of hydrogen gas, arising from the decomposition of the water. Its oxygen unites with the zinc, and the hydrogen adheres mechanically to the surface of the plate. Now immerse in the liquid a plate of clean copper, C, of the same size as the zinc. No obvious action will take place until the copper is connected with the zinc by a metallic rod, M, when we observe,

Fig. 329.



1st. Bubbles of *hydrogen gas* are evolved from the copper, but no gas is evolved from the zinc.

2d. The copper is not acted upon by the liquid, but the zinc wastes away, and the liquid is found to contain *oxide of zinc.* Hence we infer that water has been decomposed, the oxygen uniting with the zinc, and its hydrogen escaping from the copper.

3d. When the rod M is lifted, a *minute spark* is perceived.

4th. If the plates be connected by a very fine platinum wire, half an inch in length, the wire will become *red-hot.*

5th. If, instead of a metallic rod, the plates are connected by a glass rod, or any *non-conductor of electricity,* no such effects take place. This indicates that the power which is here developed is electricity.

590. *Simple Voltaic circle.* Vitreous or positive electricity flows from the zinc through the liquid to the copper, thence through the connecting wire back again to the zinc, performing a complete circuit. Resinous or negative electricity flows in the contrary direction. This is called a *simple Voltaic circle.*

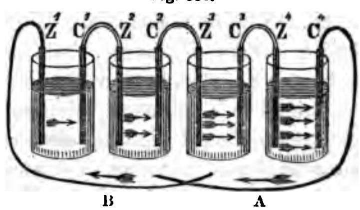
The sulphuric acid dissolves off the oxide as fast as it is formed on the surface of the zinc, thus presenting always a fresh me-

tallic surface. *The origin of the electric current is due to the decomposition of the water.*

In Grove's battery, the hydrogen is not evolved from the surface of the platina, as in the experiment last described. The hydrogen is taken up by the nitric acid, which loses a part of its oxygen, and copious fumes of nitrous acid are evolved.

591. *Compound Voltaic circles.* The electricity developed by a simple circle is extremely feeble, but its power may be increased almost without limit by combining in a single series a number of such circles in such a manner that the positive electricity developed by each circle shall flow toward one end of the series, and the negative toward the other end. *Fig.* 330 represents several simple Voltaic circles united in a series, each circle consisting of zinc and copper immersed in diluted acid. The positive electricity developed in the first circle collects upon C^1, from which it flows along the connecting wire to Z^2, and thence passes to C^2. But electricity is also developed in the second circle, the positive electricity collecting on C^2, and uniting with the positive fluid which has already passed from the first circle. The positive fluid accumulated upon C^2 passes along the wire to Z^3 and accumulates on C^3, together with the positive fluid developed in the third combination. Thus all the positive fluid developed in the different cups flows toward the last copper element C^4, while all the negative fluid flows to the first zinc element Z^1. If a wire proceeding from C^4 be brought in contact with a wire proceeding from Z^1, the entire current will pass along the wire from C^4 to Z^1. If we assume that each combination develops an equal quantity of the electric fluid, the intensity of the current will be proportional to the number of combinations in the battery.

Fig. 330.



592. *Poles of the battery.* The terminations of the connecting wires A and B are called the *poles* of the battery. A is called the *positive pole*, and B the *negative pole*. Faraday calls these poles electrodes (ηλεκτρον and οδος), implying that these points are simply the *doors* by which the current enters and departs, in

opposition to the idea once entertained that liquids are decomposed by the *attraction of the poles* of the battery for their separate elements.

593. *Difference between frictional and Voltaic electricity.* The electricity of the Voltaic battery differs from that of the common electrical machine in three particulars:

1st. In its *low intensity.* A battery of 50 elements produces but a slight divergence in the gold-leaf electrometer, and through ordinary air the spark will not pass more than one or two hundredths of an inch. A Voltaic battery with 1000 pairs of plates will not exhibit electric repulsion so decidedly as a small stick of sealing-wax rubbed with fur.

2d. In its *large quantity.* If we measure the quantity of electricity developed in a machine by the effect it will produce in decomposing water, then a simple Voltaic circle which might be contained in a common thimble, develops a *greater quantity* of electricity than a gigantic electrical machine. Faraday has estimated that a zinc wire $\frac{1}{18}$ of an inch in diameter, and immersed to the depth of $\frac{5}{8}$ of an inch in diluted acid, in three seconds of time yielded as much electricity as a Leyden battery charged by 30 turns of a plate-glass machine 50 inches in diameter.

An increase in the *size of the plates* increases the *quantity*, but not the intensity of the electricity. An increase in the *number of the plates* increases the *intensity* of the electricity, but not its quantity.

3d. In its *continuous current.* When the poles of the battery are connected by a wire, there is a current of electricity which flows uninterruptedly until the battery is exhausted by its own action, and this may continue with considerable energy for many weeks.

The effect of a Voltaic battery is in many respects similar to that of a Leyden battery of large dimensions feebly charged.

SECTION II.

CHEMICAL, ETC., EFFECTS OF THE VOLTAIC CURRENT.

594. *Conducting power of metals.* It has been determined by experiment that the resistance which a metallic conductor offers to the passage of an electric current, increases directly as its *length*, and inversely as the *area of its section.* The following table shows the relative capacity of different metals for conducting electric currents.

Silver	108	Tin	18
Copper	100	Platinum	16
Gold	83	Iron	16
Zinc	32	Lead	10
Brass	30	Mercury	3

Hence it appears that a copper wire of 100 feet in length offers the same resistance to an electric current as an equally thick wire of platinum 16 feet in length, or of lead 10 feet in length.

595. *Conducting power of liquids.* The following table shows the relative conducting power of some liquids, referred, however, to a *different standard* from the former.

Saturated solution of sulphate of copper	100
Sulphuric acid of 1.2 specific gravity	254
Water with $\frac{1}{100}$ part of common salt	52
Distilled water	$\frac{1}{4}$

The conducting power of liquids is extremely small in comparison with that of metals. The conducting power of copper is *sixteen million times* greater than that of a saturated solution of sulphate of copper; yet, by increasing the area of the section of a liquid conductor, we may render its conducting power equal to that of a metal. A copper cylinder one inch in diameter has the same conducting power as a cylinder of salt water about 500 feet in diameter.

596. *Wire melted by the Voltaic current.* When a Voltaic current passes along a small metallic wire, the wire becomes *heated;* and if the intensity of the current be sufficiently great, the wire will be fused or *burned.* The same current which will produce only a slight elevation in temperature in a wire of a certain diam-

eter, will render a finer wire incandescent, and will fuse or burn one which is still finer.

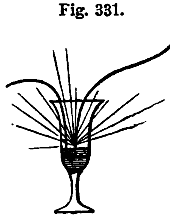
If the poles of a Grove's battery of 24 pairs be connected by a fine iron or platinum wire one foot in length, the wire will become *red hot.* If its length or thickness be diminished, it will *fuse* or *burn.* The same current which will but slightly raise the temperature of a silver or copper wire, will fuse a platinum wire of the same length and thickness.

597. *Combustibles ignited.* The heat developed by a Voltaic current may be employed to ignite combustibles or explosive substances. If a platinum wire heated by a Voltaic current be brought near the surface of ether or alcohol, these substances are immediately *ignited;* or if it be applied to gunpowder, the powder is instantly *exploded.*

If a small platinum wire be inserted in a canister of powder, and the current of a Voltaic battery be passed through the wire, the wire is heated and the powder is fired. Gunpowder may be fired at a distance of *half a mile or more* from the battery; and if the conducting wires are insulated by being covered with gutta percha, the operation may be effected with equal facility *under water.* This principle has been applied with great advantage in engineering operations, both civil and military.

598. *Spark produced by the Voltaic current.* If we unite the wires connecting the two poles of a battery, a small *white spark* will be seen, accompanied by a faint *hissing noise.* If we plunge the end of one of the wires into a vessel of mercury, and bring the other near the surface of the metal, a bright spark is emitted. If we attach a slender steel wire to one pole of the battery, and touch the wire to the surface of mercury connected with the other pole, the steel is instantly *burned.* A watch-spring is thus rapidly consumed. If water be poured upon the mercury, the spark may be obtained from the surface of the mercury *under water.*

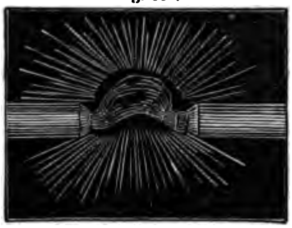
Fig. 331.



599. *The electric light.* The most brilliant light which can be produced by art is obtained when the poles of the battery are united by two pieces of hard charcoal. The charcoal best adapted for this experiment is that which is obtained from the residuum of coke in the retorts of

gas-works. This is formed into pencil-shaped cylinders three or four inches in length, and one is secured to each of the wires connecting the poles of the battery. The charcoal, being an imperfect conductor, is rendered intensely luminous by the current. When the points are separated to a short distance, a splendid flame will pass between them, as represented in *Fig.* 332. If the pole of a bar magnet be brought near the flame, it will assume a *curved form*, and the action of the magnet may be so intense as to extinguish the flame altogether.

Fig. 332.



The light produced in this experiment is *not due to the combustion of charcoal.* The incandescence is still more intense in a vacuum, or in any of the gases which do not support combustion.

600. *Metals melted and burned.* If, in place of one of the pencils, we substitute a piece of charcoal in the form of a small cup, and place a small piece of gold or platinum upon it, then, upon bringing near it the other pencil, the metal may be fused, or even *burned*, by the intensity of the electric flame.

Fig. 333.

If the Voltaic current be transmitted through a thin metallic leaf, the metal will be burned, and the color of the flame will vary with the metal. Gold leaf burns with a bluish white light, and produces a dark brown oxide. Silver leaf burns with a bright emerald green flame, and zinc with a dazzling white light. Copper burns with a bluish green flame, and emits a green smoke.

601. *Voltaic shock.* If a person moisten his hands with salt water, and grasp the wires connecting the two poles of a battery, he will perceive a sharp convulsive shock when the current commences to pass, and also when the current ceases. During the continuance of the current, he will experience a series of lesser shocks rapidly succeeding each other. The severity of the shock depends upon the *number of the plates*, and not upon *their size.*

To produce any sensible effect, from 10 to 15 pairs of plates are necessary. A battery of 50 to 100 pairs produces a violent shuddering of the fingers, arms, and chest, and if there be a sore spot on either of the hands, a burning sensation will be produced at that point.

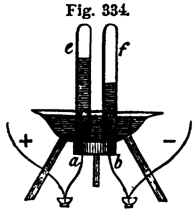
If several persons moisten their hands with salt water, and then join hands, the shock may be transmitted through the *entire series* at once. The shock may be easily confined to any part of the human system, and it has been found to be serviceable in certain classes of diseases.

If the current of a Voltaic battery be passed through the body of a man or animal recently deprived of life, the muscles will be *violently convulsed.* The arms and legs may thus be made to move rapidly, the eyes may be made to open and close, while the mouth and all the features of the face move as if writhing in pain.

602. *Decomposing power of a Voltaic current.* When a Voltaic current of sufficient intensity is made to pass through a compound liquid body, the compound is generally resolved into its elements, which appear to be transported in contrary directions, one *with* and the other *against* the course of the positive current. One is liberated at the positive pole, and the other at the negative pole of the battery.

Water is composed of two gases, oxygen and hydrogen, in the proportions by volume of one part of oxygen and two of hydrogen. Take two glass tubes, *e* and *f*, closed at one end, fill them with dilute acid, and, stopping the open ends, invert the tubes in an open vessel containing also dilute acid. Let two platina wires, *c* and *d*, be connected with the poles of a Voltaic battery, *a* and *b*; let the wire *c* be inserted a short distance in the tube *e*, and the wire *d* in the tube *f*. As soon as the Voltaic circuit is complete, small bubbles of gas will issue from the points of the wires, and will rise in the tubes *e* and *f*; but twice as much gas will be collected in one tube as in the other. When a sufficient amount of gas is collected, if we introduce into the tube *e* a small candle whose flame is just extinguished, it will be relighted, showing that this tube contained *oxygen.* If we mix a small quantity of atmospheric air with the

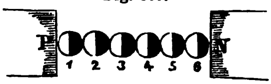
Fig. 334.



gas in the tube, and apply a spark, there will be an explosion, showing that this tube contained *hydrogen*.

603. *Mode of decomposition.* In this experiment, gas is evolved only on the wires *c* and *d*, and no bubbles are seen throughout the intervening liquid. This fact has been explained as follows: Let 1, 2, 3, etc., represent a series of particles of water, each consisting of an atom of oxygen combined with an atom of hydrogen. The positive electricity entering the liquid at P, decomposes the first particle of water; the atom of oxygen is liberated, while the atom of hydrogen unites with the oxygen of the second particle, 2. The hydrogen of the particle 2 unites with the oxygen of 3, the hydrogen of 3 with the oxygen of 4, and so on to the last particle, 6, whose hydrogen is set free. Thus a constant decomposition and recombination of the particles of water goes on along the whole line between the poles, but it is only at the poles that its constituents can be liberated.

Fig. 335.



By means of the Voltaic current a large number of compound bodies have been decomposed.

604. *Electro-plating.* The decomposing power of the Voltaic current has been applied to various useful purposes, such as *electro-plating*, *electro-type*, etc. Articles made of the baser metals may be beautifully gilded or silvered by the action of electricity. Suppose a silver spoon is required to be gilded. The spoon is first connected with the negative pole of a battery, while a plate of gold is connected with the positive pole. Both are then immersed in a solution of the chloride of gold. The chloride is decomposed, the gold is deposited as a coating on the spoon, and the chlorine, combining with a corresponding portion of the gold connected with the positive pole, maintains the solution at a uniform degree of strength.

By a similar process, a coating of silver or copper may be deposited.

If the body to be coated be formed of a material which is a *non-conductor*, the power of conduction may be imparted to its surface by coating it with finely-powdered black-lead. Statues in plaster can thus be reproduced in metal with the greatest precision, and at an expense not much exceeding that of the metal of which they are formed.

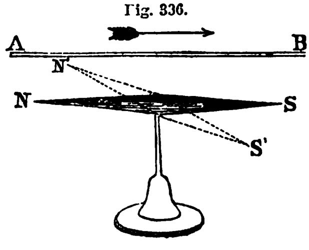
605. *Electrotype.* A mould in plaster of Paris or in wax being taken from a wood-engraving or from a page of printer's type, it may be copied in copper by means of a Voltaic current. The mould, having been first coated with finely-powdered black-lead, is placed in a solution of sulphate of copper, and connected with the negative pole of a Voltaic battery. A mass of copper is attached to the positive pole. By the action of the Voltaic current the sulphate of copper is decomposed, and metallic copper is precipitated on the mould, incrusting it with a tough coat. The back of this copper coat is now filled with melted lead, and we thus obtain a stereotype plate with letters of remarkable sharpness formed of copper. The plates from which this book was printed were electro-typed by this process.

SECTION III.

ACTION OF A VOLTAIC CURRENT AND A MAGNET UPON EACH OTHER.

606. *Œrsted's discovery.* In the year 1819, Professor Œrsted, of Copenhagen, discovered that a wire, AB, conducting an electric current, has the power of deflecting a magnetic needle, the needle always tending to take a position at right angles to the wire. If the direction of the current be reversed, the needle still takes a position at right angles to the conducting wire; but the north pole of the needle now turns in the contrary direction from what it did at first. The force which emanates from the conducting wire is not exerted either directly *toward* the wire, or directly *from* it, but rather in a plane *perpendicular* to the wire, and produces motion in a circular direction all round the wire. The conducting wire is hence said to exert a *tangential action.*

Fig. 336.



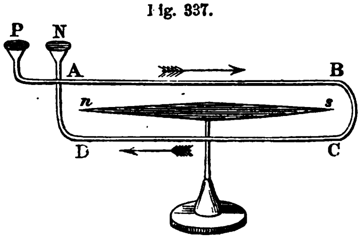
607. *Direction in which the magnet is deflected.* As the conducting wire and the magnetic needle may occupy an infinite variety of relative positions, it is important to have some convenient rule which will invariably indicate the direction in which the north

pole of the magnet is deflected. Such a rule has been given by Ampère. *If you conceive yourself lying in the direction of the current, the stream of positive electricity flowing through your head toward your feet, with the north pole of the magnet before you, the north pole will always be deviated toward the right.*

This rule, if properly applied, will, in every instance, enable us to predict in what direction the north pole of a magnet will be deviated, and the student should accustom himself to apply the rule to the cases which follow. When the north pole of a magnet is deflected toward the *right*, the south pole is, of course, deflected toward the *left*.

608. *The Galvanometer.* Professor Œrsted's discovery affords us a new means of detecting the presence of an electric current; and it has been so applied as to indicate currents of the feeblest kind. If the conducting wire ABCD be bent so as to form an oval surrounding the needle, the current which is below the needle will deflect the north pole in the *same direction* as the current which is above the needle. Both portions of the wire also conspire to urge the south pole in the contrary direction, so that the needle is deflected with *twice the force* which a straight wire would have exerted. If the wire be coiled twice round the needle, the deflecting force of the current will again be doubled; if the wire be coiled a hundred times round the needle, the deflecting force will be multiplied a *hundred fold.* In this case, the wire conducting the current must be covered with silk, or some other insulating substance, to prevent the direct passage of the current from one coil to another.

Fig. 337.



Such an apparatus has been called a *multiplier*, in consequence of its multiplying the effect of the current. It has also been called a *Galvanometer*, inasmuch as it supplies the means of measuring the force of the electric current. The two extremities of the wire of the galvanometer must remain free, so that any required current may be transmitted through the whole length of the wire. The needle is suspended by a thread of untwisted

silk; a graduated circle is placed immediately beneath the needle, and the apparatus is protected from currents of air by a glass cover. When the instrument is to be used, it should be placed so that the plane of the coils of the wire may coincide with the magnetic meridian. When no current is passing, the needle will then rest in the plane of the coil; but the passage of a current through the coil causes an instant deflection of the needle.

609. *Astatic galvanometer.* The sensibility of the galvanometer is very much increased by employing two needles with their poles turned in contrary directions, the two needles being connected by a fine wire. If the magnetism of the two needles were equal, the directing force of the earth's magnetism upon the combined needles would be zero, and the system would be entirely indifferent to the earth's magnetism. Such a combination is called *astatic.* The distance between the two needles must be such as to allow one needle to swing freely within the coil of wire, and the other over the coil, as shown in *Fig.* 339. In this case the action of the Voltaic current upon the upper needle is the reverse of its action upon the lower needle; but since the poles are also in the reversed position, both needles tend to turn in the *same direction.* It is most convenient to make the directive power of the two needles *slightly unequal,* the difference being barely sufficient to bring the compound needle into a constant position when uninfluenced by any electric current.

Fig. 338.

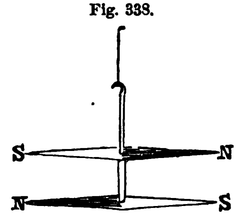
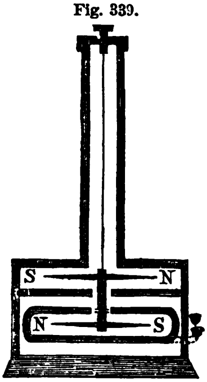


Fig. 339.

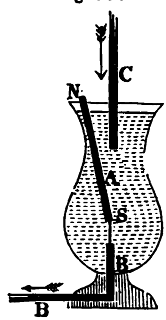


The galvanometer affords the means of detecting the feeblest electric current. If a zinc and platinum wire $\frac{1}{50}$th of an inch in diameter be immersed to the depth of $\frac{1}{8}$th of an inch in a drop of water acidulated with sulphuric acid, a current will be developed which will sensibly affect the galvanometer.

610. *Revolution of a magnet round a conducting wire.* Since a wire conveying an electric current always tends to urge the north

pole of a magnetic needle toward the right, the wire and magnet may be so arranged that the current shall produce a continued revolution of one of the poles of a magnet around the conducting wire. *Fig.* 340 represents a glass vessel nearly filled with mercury. A is a cylindrical magnet tied by a fine thread to the conducting wire BB, which passes through the bottom of the vessel. The wire C communicates with one of the poles of a Voltaic battery, so that a current may be made to pass down the wire C, through the mercury, and thence by the wire BB to the battery. This current impels the pole N of the magnet to the right, and causes it to revolve round the wire in the direction of the hands of a watch. If the current be reversed, the pole N will revolve in the contrary direction.

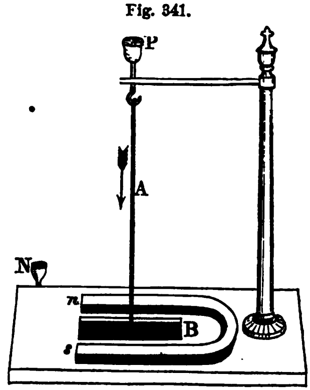
Fig. 340.



611. *Action of a magnet upon a conducting wire.* Since a wire conveying an electric current acts upon a magnetic needle, the magnet must react upon the wire, impelling it in the *opposite direction.* If, then, the magnet were fixed and the wire movable, the motions of the latter would be just the reverse of the former. There are various modes of exhibiting these effects.

In *Fig.* 341, A represents a platinum wire suspended by a loop from a copper wire connected with a small cup, P, containing mercury. The lower end of the wire dips into a small cistern of mercury, B, which communicates by a wire with a small cup, N, also containing mercury. The wire A hangs freely between the two poles, *n* and *s*, of a horse-shoe magnet. When a Voltaic current passes along the wire A, it impels the pole *n* of the magnet toward the right, and the reaction of the magnet on the current impels the wire toward the left. The pole *s* of the magnet conspires with the pole *n*, impelling the wire in the *same direction.* The wire is

Fig. 341.

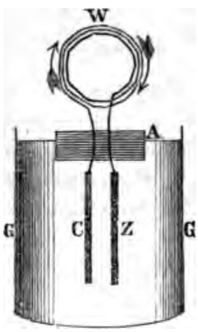


thereby thrown out of the mercury. The current being thus broken, the effect ceases until the wire, by its own weight, falls back again into the mercury, when the same phenomenon is repeated, and the wire *vibrates back and forth* with great rapidity.

By an arrangement similar to that of Art. 610, we may produce a continued revolution of the conducting wire about the pole of a magnet.

612. *Action of a magnet upon a conducting ring.* If a wire conducting an electric current be bent into the form of a circle, one face of the circle will be attracted by the north pole of a magnet, and the other by its south pole.

Fig. 343.



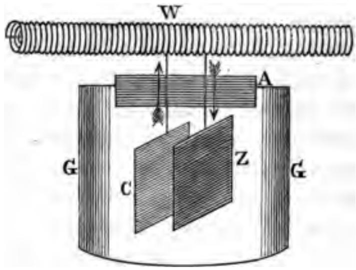
Let C and Z represent the two plates of a small Voltaic battery, attached to a cork, A, of sufficient size to cause the plates to float in dilute acid; and let the plates be joined by a copper wire, W, bent into the form of a circle. A current of electricity will thus be made to flow from the copper plate, along the circular wire, back to the zinc plate. When we look on one side of the plane of the circle, the current will appear to circulate in the direction of the hands of a watch; but if we look on the other side, the current will appear to circulate in the contrary direction. If the north pole of a magnet be presented to the former side of the circle, the wire *will be attracted* by the magnet; if the south pole be presented to the same side of the circle, the wire *will be repelled.*

By using a longer wire, and coiling it *several times* round in a circle, the effect of the magnet will be very much increased.

613. *Action of a magnet upon a conducting spiral.* The effects are still more remarkable if the wire be coiled spirally round a cylindrical surface. Let the wire from the copper plate (*Fig.* 343) be inserted in an opening made in the side of a hollow cylinder (a long quill, for example), and let it pass along the axis to one end of the cylinder. Let it then be wound spirally round the outside of the cylinder along its whole length, and, proceeding back along the axis of the cylinder, let it be brought out near the middle, and be joined to the zinc plate of the battery. The

current will thus be made to flow through the whole length of the wire, and the current in each coil will flow in the same direction. One end of such a cylinder will be powerfully attracted by the north pole of a magnet, and repelled by its south pole. This arrangement has been termed

Fig. 343.



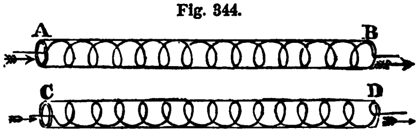
by Ampère an *electro-dynamic cylinder*, and appears to possess the essential properties of a magnet. So sensitive is this instrument that the force of terrestrial magnetism is sufficient to direct it, and, when left to itself, *it invariably comes to rest with its axis in the magnetic meridian.*

SECTION IV.

MAGNETISM DEVELOPED BY A VOLTAIC CURRENT.

614. *Soft iron rendered magnetic.* We have seen, Art. 607, that when a magnetic needle is brought near a wire conducting an electric current, the current acts upon the magnet, impelling the north pole toward the right. An unmagnetized bar of steel placed transversely upon the wire, immediately becomes magnetic, one extremity being a north pole, and the other a south pole. A piece of soft iron under the same circumstances becomes a temporary magnet, and will attract iron filings. If the wire be coiled several times spirally around the iron, the magnetic action will be greatly increased. Such a spiral is denominated a *helix.* A helix is *right-handed* when the convolutions run in the same way as in an ordinary screw; a helix

Fig. 344.

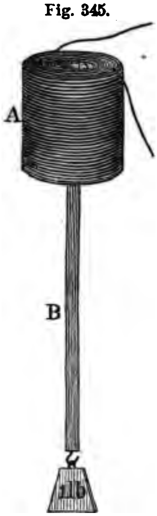


is *left-handed* when the convolutions run in the contrary direction. To prevent direct communication between the coils of the wire, the conducting wire should be covered with silk. By

multiplying the coils of the helix, the magnetic effect may be increased almost indefinitely.

615. *Action of an heliacal current.* If an unmagnetized bar of steel be introduced into a helix, and an electric current be transmitted through the helix, the bar instantly becomes a permanent magnet. The bar need not remain beyond a moment in the helix, for the magnetizing effects are produced *almost instantaneously.* A bar of soft iron under the same circumstances becomes a temporary magnet.

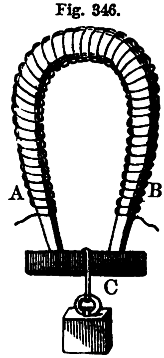
Fig. 345.



If the helix A be held with its axis in a vertical position, the iron bar B will be sustained by the action of the current. With a large battery and a long coil, a considerable weight may be suspended from the bar, and the whole will be sustained without any visible support. As soon as the electric current ceases, the magnetism disappears. Temporary magnets thus produced by an electric current are called *electro-magnets.*

616. *Powerful electro-magnets.* The most powerful electro-magnets are formed by bending a thick cylinder of soft iron, AB, into the form of a horse-shoe, and surrounding it with a coil of insulated copper wire. When a Voltaic current is passed through the wire, the iron becomes powerfully magnetic, and will lift a heavy weight by means of an armature, C, of soft iron applied to its poles. In an experiment made by Professor Henry, a horse-shoe of soft iron was wound with 728 feet of copper bell-wire. With a battery presenting five square feet of zinc surface, this magnet supported 2063 pounds. Electro-magnets have been made which would sustain a weight of 4000 pounds. If we reverse the direction of the current, the poles will be instantly reversed. As soon as the current ceases, the magnetism disappears almost instantly.

Fig. 346.

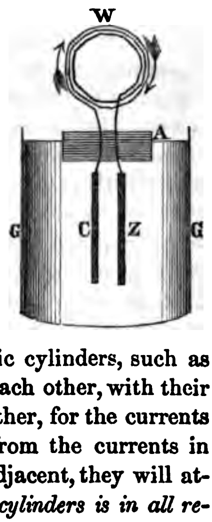


SECTION V.

RECIPROCAL INFLUENCE OF VOLTAIC CURRENTS.

617. *Two wires conveying an electric current attract each other when the currents flow in the same direction, but repel if they flow in opposite directions.* This may be shown experimentally by means of the apparatus represented in *Fig.* 347. Suppose the current to circulate through the wire in the direction shown by the arrows. If a second wire, conveying also an electric current, be brought near the former, there will be attraction when both currents flow in the same direction, but repulsion when they flow in contrary directions.

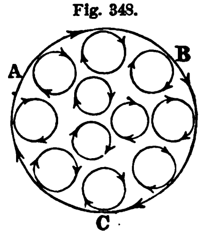
Fig. 347.



618. *Mutual action of electro-dynamic cylinders.* These effects will be increased by multiplying the number of currents, which may be done by employing a long wire coiled into the form of a ring, or wound spirally round a cylinder. If two electro-dynamic cylinders, such as were described in Art. 613, be brought near each other, with their similar ends adjacent, they will repel each other, for the currents in one coil flow in the contrary direction from the currents in the other coil. If the dissimilar ends are adjacent, they will attract each other. Hence *the action of these cylinders is in all respects like that of permanent magnets.* Upon this fact Ampère has founded his theory of magnetism.

619. *Voltaic theory of magnetism.* According to Ampère's theory, a magnet is to be regarded as composed of an assemblage of particles, round each of which currents of electricity are continually circulating in one uniform direction. Let ABC represent the section of a permanent magnet, and suppose electric currents to circulate round its particles in the direction indicated by the arrows, the currents of the interior will nearly, if not wholly, neutralize

Fig. 348.



each other; but the currents near the circumference are equivalent to a single circular current flowing round the magnet. If the south pole of a magnet be turned toward the observer, the current will appear to circulate in a direction similar to that of the hands of a watch. If the north pole be turned toward the observer, the current will circulate in the contrary direction. If the north pole of one magnet be presented to the north pole of another magnet, the adjacent currents in the two magnets will circulate in *contrary directions*. If the north pole of one magnet be presented to the south pole of another magnet, the adjacent currents in the two magnets will circulate in the *same direction*. According to Ampère's hypothesis, the repulsion between the similar poles of two magnets is explained by the repulsion between the two electric currents flowing in opposite directions; and the attraction between dissimilar poles is explained by the attraction between the two currents flowing in the same direction. This hypothesis also explains how, when a magnet is divided into several parts, each portion is a perfect magnet; it also explains the effect of an electric current upon a magnet, and of a magnet upon an electric current. In short, whether this hypothesis be true or not, *it has the merit of explaining nearly, if not quite, all the known phenomena of permanent magnets.*

620. *Momentary currents by induction.* If a wire connecting the two ends of a galvanometer be placed parallel, and close to a second wire connecting the poles of a Voltaic battery, no effect will be produced upon the needle so long as the current through the second wire is uninterrupted. When, however, the current of the battery is stopped, the needle of the galvanometer is momentarily deflected, as by a wave of electricity passing in the same direction as that of the main current. After the needle has come to rest, if the contact be renewed, the needle will be deflected in the contrary direction. Hence we see that *a Voltaic current circulating in one wire induces a current in a neighboring wire at the instants of making and breaking contact.* In the first case, the induced current is in the *contrary* direction to the inducing current; but in the second case it is in the *same* direction.

621. *Magnetism developed by secondary current.* The currents thus excited are sufficiently powerful to induce magnetism in steel bars not previously magnetic. If an unmagnetized steel

needle be introduced into a helix connected with the second wire, and the poles of the battery be joined by the first wire, the needle will be found magnetized. If the battery contact be first made, and an unmagnetized steel needle be then introduced into the helix, and the battery contact be broken, the needle will be magnetized; but the position of the poles will now be *opposite* to what it was before.

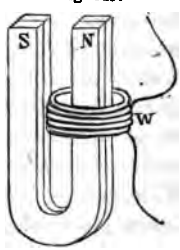
If we employ long insulated wires coiled many times round a cylinder, the induced currents become very powerful, and furnish a *brilliant spark* as well as *severe shocks*.

SECTION VI.

ELECTRIC CURRENTS EXCITED BY A MAGNET.

622. We have seen that an electric current passing through one wire induces a current in a neighboring wire at the instants of making and breaking contact. In like manner, a permanent magnet will develop currents in a conducting wire.

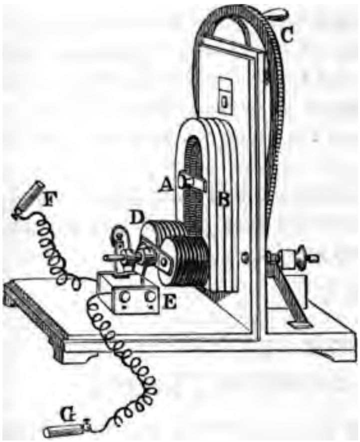
Fig. 349.



If we take a long insulated wire, W, coiled into a helix, and having connected its extremities with a galvanometer, thrust one pole of a permanent magnet, N, through the coil, a momentary deflection of the needle will be produced. If, after the needle has come to rest, we suddenly withdraw the magnet, the needle will be again deflected in a direction *contrary* to what it was at first.

623. *Magneto-electric machine.* An apparatus has been constructed for exhibiting these effects in a striking manner. For this purpose we employ a compound horse-shoe magnet, AB (*Fig.* 350), secured to a fixed frame, and by means of a multiplying wheel, C, an armature, DE, is made to revolve rapidly before the poles of this magnet. This armature consists of two pieces of soft iron connected at right angles to a third piece, together forming a species of horse-shoe. Round the branches of this armature is wound a fine insulated copper wire about one mile in length. The ends of the wire are so adjusted that the circuit may be closed or opened at pleasure.

Fig. 350.



When the armature is revolved before the pole of the magnet, a current of electricity is induced in the coil of wire, and the direction of the current changes at every half revolution of the armature. On revolving the armature with rapidity, the current is sufficient to give *severe shocks*, to *decompose water*, and to *magnetize bars of steel.* The handles F and G are for the purpose of communicating the shock.

624. *Currents induced in a revolving metallic disk.*

In 1825, Arago discovered that, if a magnetic needle be vibrated over a plate of metal, such as copper or zinc, its *arc of vibration* was rapidly diminished, and the needle soon came to rest; yet the *time of one vibration* remained unchanged. He also ascertained that, if the copper plate be rapidly revolved in a horizontal plane beneath the magnetic needle, *the needle will be deflected* from its mean position, and the velocity of rotation may be so increased that the needle shall be carried round through an entire circumference in the same direction as that of the plate. This motion is not due to *currents of air*, for the same effect takes place when a screen of parchment is interposed between the needle and the plate.

These phenomena are explained by the principle of Art. 622. When a copper plate is revolved near the pole of a magnet, momentary currents of electricity are induced in the plate, and these currents act upon the magnetic needle according to the principles explained in Art. 607.

625. *Frictional electricity and Voltaic electricity identical.* The electricity excited by a common electrical machine is identical with that of the Voltaic battery, for the two agents produce in every instance the *same classes of effects.* These effects are,

1. Attraction and repulsion.

2. The spark.
3. The charge of a Leyden jar.
4. The shock.
5. Development of heat.
6. Development of magnetism.
7. Chemical decompositions.

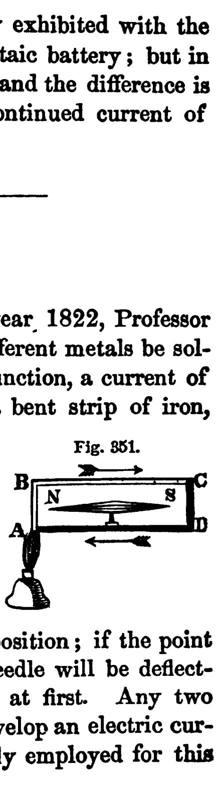
Some of these effects are most strikingly exhibited with the common machine, and others with the Voltaic battery; but in both cases the effects are of the same kind, and the difference is probably due to the feeble intensity and continued current of the Voltaic battery.

SECTION VII.

THERMO-ELECTRICITY.

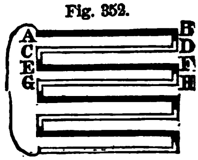
626. *Thermo-electric rectangle.* In the year 1822, Professor Seebeck, of Berlin, discovered that if two different metals be soldered together, and heat be applied at the junction, a current of electricity will be excited. Let ABC be a bent strip of iron, and ADC a similar strip of tin soldered to the iron so as to form a rectangle, ABCD. Let NS be a magnetic needle, movable freely within the rectangle, and let the apparatus be so placed that the plane ABCD may coincide with the magnetic meridian. If the point A be *heated by a spirit-lamp,* the needle will be deflected from its mean position; if the point A be *cooled* by the application of ice, the needle will be deflected in a direction *contrary* to what it was at first. Any two metals arranged in a similar manner will develop an electric current; but the two metals which are chiefly employed for this purpose are bismuth and antimony.

Fig. 351.



627. *Thermo-electric pile.* These effects may be greatly increased by combining a large number of thermo-electric elements. Let AB be a bar of bismuth, CD a bar of antimony soldered to it; EF a bar of bismuth, GH of antimony, etc. If a hot iron

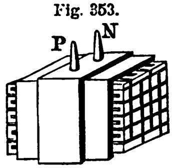
Fig. 352.



be laid upon the ends BDFH, while the ends ACEG are cooled with ice, a current will be developed whose intensity is equal to the sum of the intensities of the separate elements; while, by means of a wire proceeding from the first bar of bismuth, AB, and another wire proceeding from the last bar of antimony, the current may be directed at pleasure.

When thirty or more such combinations are required, they are most conveniently arranged as shown in *Fig.* 353, which is called the *thermo-electric pile*. The first bar of bismuth communicates with the wire P, and the last bar of antimony communicates with the wire N. P and N form the two poles of the pile, and they are connected with the ends of the galvanometer wire.

Fig. 353.



If the soldered points on one side of the pile experience the slightest elevation of temperature, the galvanometer needle will at once deviate from the magnetic meridian. This apparatus has been made so sensitive that the warmth of the hand, at the distance of thirty feet, was sufficient to affect the galvanometer.

If one end of the pile rests upon a cake of ice, and a hot iron be applied to the other end, a current of electricity will be developed, which, by means of a helix of copper wire, will yield a *vivid spark*, and produce powerful *magnetic effects.*

628. *Source of the earth's magnetism.* Since the surface of the earth is unequally heated in different latitudes, and also, at each spot, the temperature changes with the hour of the day, it has been inferred that electric currents must be thereby developed in the crust of the earth, and it has been supposed that these currents might be the source of the earth's magnetism. If there were electric currents circulating round the globe from east to west in planes parallel to the magnetic equator, the effect of such currents would every where be to cause the magnetic needle to assume a position corresponding very nearly with what is actually observed. Observation has actually indicated the existence of such currents in the mining districts of England, but we have no direct evidence of the existence of a general current extending entirely round the globe. It has, however, been supposed that such currents must necessarily result from the *heating action of the sun's rays* traveling daily round the globe from east to west.

SECTION VIII.

APPLICATIONS OF VOLTAIC ELECTRICITY.

629. *Morse's electric telegraph.* The most important application of electricity to the uses of life is the electric telegraph. There are various forms of the electric telegraph, but the one chiefly employed in America and upon the Continent of Europe is that of Professor Morse, which was patented in 1837, and first put in operation between Washington and Baltimore in 1844. This telegraph consists of three distinct parts:

1st. A Voltaic battery to generate electricity;

2d. Insulated conducting wires to convey the electric current to any required distance;

3d. A register to record the signs which are employed to represent the letters of the alphabet.

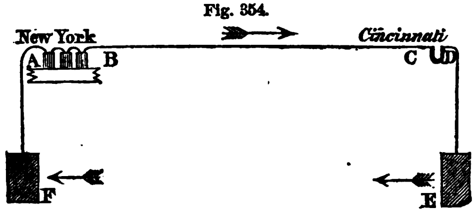
To generate the electric current, Grove's battery is usually employed. The amount of battery required depends upon the distance. For telegraphing a distance of 100 miles, a battery of about 25 cups is generally found necessary.

630. *Conducting wires.* In order that the conducting wire may not dissipate the electricity, it must be insulated. This is sometimes effected by coating the wire with gutta percha, and then the wire may be buried in the ground, or sunk to the bottom of the sea. More commonly the wire is attached to glass knobs, supported by wooden posts from 20 to 30 feet high. The wire requires no other insulation, and, on account of its greater strength as well as cheapness, iron wire is preferred to copper.

631. *The earth completes the circuit.* We will suppose it is required to transmit a telegraphic message from New York to Cincinnati. It is not sufficient to have merely one conducting wire reaching from New York to Cincinnati. There must be a second conductor returning from Cincinnati to New York, for the Voltaic current will not circulate unless the circuit is complete from one pole of the battery to the other. When the electric telegraph was first proposed, it was considered necessary to have a second wire extending from the distant station back to the point of start-

ing; but it was soon discovered that the *earth itself* was not only the cheapest, but the best conductor which could be employed for the returning current of electricity. The arrangement now universally adopted is represented in *Fig.* 354, where A represents the Voltaic battery at New York; BC is an insulated wire going from New York to Cincinnati; D is the register at Cincinnati; E is a plate

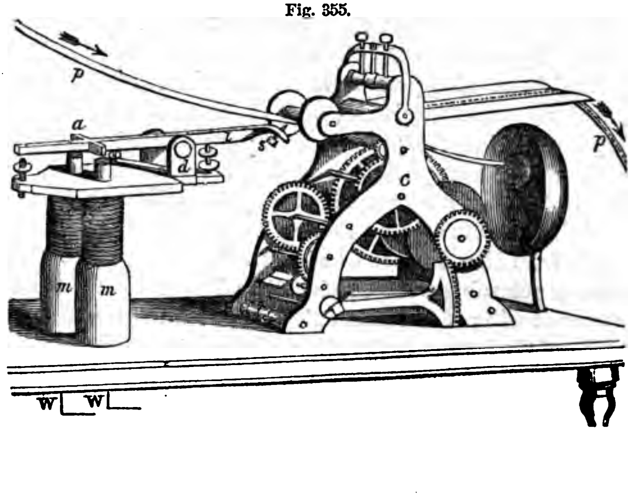
Fig. 354.



of metal having a surface of several square feet, which is buried in the moist ground, and connected with the wire at C; F is a similar plate buried in the ground at New York, and connected with the wire BC. The current will then pass from the battery A along the wire BC, thence through the plate E into the earth, thence through the earth to F, and back again to the battery at A. The slightest interruption in any part of this circuit renders telegraphing impossible.

632. *How signals are transmitted.* The signals which are transmitted by the electric current are made in the following manner. At Cincinnati is placed an electro-magnet, *mm*, wound with a great length of fine copper wire, and connected with the conduct-

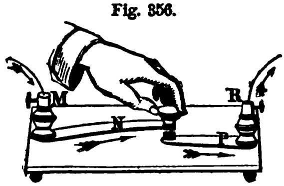
Fig. 355.



ing wire BC from New York to Cincinnati, so that, when the circuit is complete, the electricity from the battery in New York passes along the conducting wire BC, thence through the wire of the magnet *mm*, and thence through the earth back again to New York. *mm* thus becomes magnetic, and attracts the keeper *a*, which is attached to one arm of a lever, turning upon the fulcrum *d*, so that, when the keeper *a* is drawn *down*, the other end, *s*, of the lever is forced *up*. The end *s* carries a steel point, which presses against a revolving cylinder. Between this point and the cylinder, a narrow strip of paper, *pp*, is drawn by clock-work, *c*, at the uniform rate of about half an inch per second. Whenever the electric circuit is complete, the point *s* is pressed against the paper *pp*, and makes a dot or a line; when the circuit is broken, the lever falls off, and a blank space is left upon the paper.

633. *Signal key*. The operator at New York breaks and closes the electric circuit at pleasure by means of an apparatus called a *signal key*. In *Fig*. 356, N is a strip of brass, bent so as to rest a little above another brass plate, P, but not quite in contact with it. This apparatus is introduced into the electric circuit by connecting wires at M and R. By a slight pressure of the finger on the end of N, this plate is brought in contact with P, and thus the circuit is complete from New York to Cincinnati. When the finger is raised, the plate N rises by its own elasticity, and the circuit is immediately broken. Thus, when the operator at New York taps on the knob at N, the electric circuit is completed, and a dot is made on the paper *pp* at Cincinnati. If the finger continues to press on N, a continuous line will be made on the paper *pp;* and when the finger is lifted from N, there is a blank on the paper *pp*. Thus the operator at New York is able at pleasure to make dots, or lines, or blank spaces on the paper at Cincinnati. By a combination of dots and lines of different lengths, signs are formed to represent each letter of the alphabet.

Fig. 356.



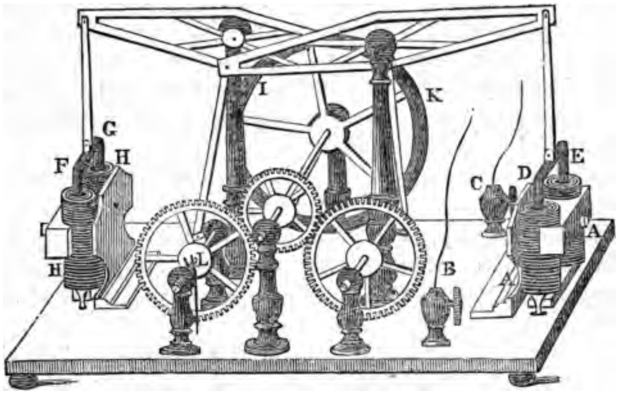
634. *Morse's telegraphic alphabet*. The following is the alphabet employed on the Morse telegraph:

				Numerals.	
A	- —	N	— -	1	- — — -
B	— - - -	O	- -	2	- - — - -
C	- - -	P	- - - - -	3	- - - — -
D	— - -	Q	- - — -	4	- - - - —
E	-	R	- - -	5	— — —
F	- — -	S	- - -	6	- - - - - -
G	— — -	T	—	7	— — - -
H	- - - -	U	- - —	8	— - - - -
I	- -	V	- - - —	9	— - - —
J	— - — -	W	- — —	0	— —
K	— - —	X	- — - -		
L	—	Y	- - - -		
M	— —	Z	- - - -		

635. *Chemical telegraph.* In Bain's telegraph the electric current is transmitted through a metallic pencil which presses against a paper which is impregnated with a *chemical solution* capable of being decomposed by the current. When this solution is decomposed, a *colored spot* is made upon the paper. This paper is carried uniformly forward by clock-work, so that, by alternately completing and breaking the circuit, an operator at a distance may trace dots or lines upon the paper at pleasure.

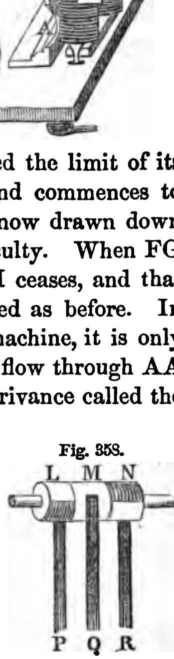
636. *The Voltaic current a moving force.* The Voltaic current is easily applied as a moving power. When a current of electricity flows through a wire coiled round a bar of soft iron, the iron instantly acquires magnetism, but loses it as soon as the current ceases; or if the direction of the current be reversed, the poles of the magnet will be reversed. This power is easily applied to the production of rotary or reciprocating motion. *Fig.* 357 represents an arrangement for this purpose, invented by Professor Page. AA represents two large coils of copper wire, through which the current of a Voltaic battery may be made to pass by means of wires attached to B and C. DE is a bar of soft iron having the form of the letter U, with each of its arms inserted in one of the helices. FG is a similar bar of soft iron working in the helices HH. Each bar is attached to one arm of a working-beam, while the other arm gives motion to a crank, which, by means of toothed wheels, communicates its motion to a fly-wheel, IK. When the Voltaic current is transmitted through the coils AA, the bar DE becomes magnetic, and is drawn down

Fig. 357.



with great force. As soon as DE has reached the limit of its motion, the current in the coil AA ceases, and commences to flow through the coil HH. The bar FG is now drawn down with great force, while BC rises without difficulty. When FG reaches its limit of motion, the current in HH ceases, and that in AA is resumed, when the motion is repeated as before. In order to produce a continued motion of the machine, it is only necessary that the current should be made to flow through AA and HH *alternately*. This is effected by a contrivance called the *cut-off*, attached to the axis L.

Fig. 358.



637. *The cut-off* consists of an axis, LMN, divided into three portions. The central portion, M, is a cylindrical piece of copper, against which the spring Q presses continually. The spring Q connects with one pole of the battery, so that the cylinder M is in constant connection with the battery. The cylinders L and N are *one half copper* and *the other half ivory*, but the copper portions of L and N are on *opposite sides* of the axis. Against these cylinders press the two springs P and R, one of which communicates (by a wire under the base-board) with the helix AA, and the other communicates with the helix HH. When the spring P rests upon the copper part of L, the current from the battery passes through Q from M to L into P,

and hence to the coil AA, which instantly becomes magnetic. When the spring P presses against the ivory part of L, the current through the helix A ceases, and the current now passes through Q from M to N into R, and hence to the helix HH, which instantly becomes magnetic. Thus the helices AA and HH are *rendered magnetic alternately*, and a continued rotation of the fly-wheel is maintained.

638. *Electro-magnetic locomotives.* In 1837, Davenport constructed an electro-magnetic machine of *one horse-power*, by means of which a newspaper was printed in New York.

In 1841, an electro-magnetic locomotive was constructed at Leipzig, in Germany, which was estimated to be equal to *seven horse-power*.

In 1851, Professor Page, of Washington, constructed an electro-magnetic locomotive, which was estimated as equal to *ten horse-power*, and which attained a velocity of *nineteen miles per hour*.

A great variety of electro-magnetic machines have been constructed, but none of them work so economically as steam, so that hitherto they have failed to come into general use.

INDEX.

THE END.

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